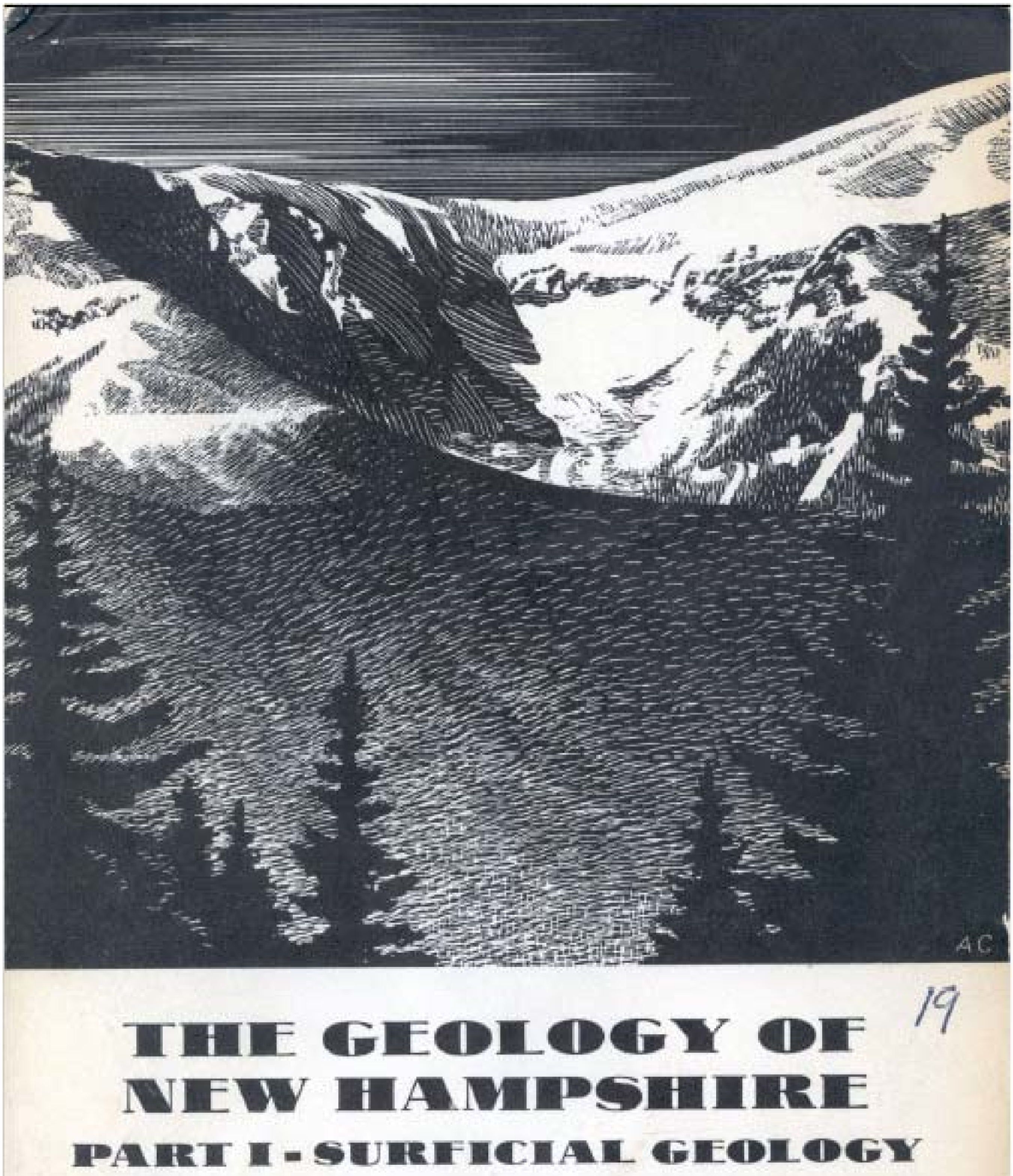

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THE GEOLOGY OF NEW HAMPSHIRE

PART I - SURFICIAL GEOLOGY

By

James Walter Goldthwait

Lawrence Goldthwait

Richard Parker Goldthwait

PUBLISHED by THE NEW HAMPSHIRE STATE PLANNING and DEVELOPMENT COMMISSION

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1951

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THE SURFICIAL GEOLOGY OF NEW HAMPSHIRE

By James Walter Goldthwait, Lawrence Goldthwait and Richard Parker Goldthwait

INTRODUCTION

This book is for the resident or traveler whose curiosity prompts the question, how were New Hampshire mountains and lakes shaped? It is for the teacher and nature lover who would know how stony fields and ridges of gravel came to be. The professional geologist may read in simple terms a summary of years of study about the glaciation of the Granite State. Naturally each one is most interested in some one mountain range or lake or township, so an index is provided at the end. However, there are many examples of each interesting feature and only a few can be mentioned. Footnotes and tables will indicate other localities where the same feature may be seen. The few technical terms used for brevity are explained where they appear in the text for the first time and in the glossary at the end. Only the first short chapter attempts to cover the intricate and interesting story of the solid bedrocks. A companion volume is planned by other authors who will give this part of the story more completely.

The *Geology of New Hampshire* written by J. W. Goldthwait in 1925 popularized the long outdated three volume *Geology of New Hampshire* by C. H. Hitchcock in 1872-78, and brought the surficial geology up to that date. Since 1925 new features have been discovered and studied. Even the techniques of study have improved. Above all, ideas and mental pictures of events thousands of years before man have changed as geological science grew. Therefore, revision of the 1925 "Handbook" was begun in 1947 by all three authors. Death of the senior author (J. W. Goldthwait) at the close of 1947 has left some of the writing and all of the editing to his sons.

Some ideas are previously unpublished; others are borrowed from students and co-workers. Some may be shown to have been in error by future study, but they are born of a flexible open-minded approach which champions the most likely ideas and will change if new evidence points in another direction. Geology is not just a body of facts but one of probabilities. In the light of modern knowledge, here are the current explanations about the fascinating scenery of New Hampshire.

DEVELOPMENT OF THE SOLID ROCK

The story of the rocks of New Hampshire begins nearly four hundred million years ago. The geologists' microscope tells us that the rocks were once grains of sand or slit or limy mud such as occur near seashores and in shallow seas today. Unique chemical and mineral composition confirms this similarity. Locally there are a few marine *fossils* in these rocks in New Hampshire. On the Fitch Farm west of Littleton, fossil-hunters have dug out cup corals, stems of sea lilies (crinoids), and lamp shells (brachiopods) for years. Not only were these animals sea dwellers, but they are known to be diagnostic of some of the older rocks such as lower layers in Grand Canyon, where the rocks of age after age are piled on top of each other in layered sequence. No animals exactly like them live today. On this evidence the fossils date back about three hundred and fifty million years to the early part of the Paleozoic Era (Silurian Period). Paleozoic means "early life." Presumably the layers just below these rocks in New Hampshire are just older, and belong to a still earlier part of the Paleozoic Era (Ordovician Period). The uppermost of these fossiliferous beds have a very few fossils which may be only three hundred million years old! By the detailed mapping of these twisted and sometimes broken layers of rock a group of geologists under Professor M. P. Billings at Harvard University has traced these ancient sediments across a large part of the State. The sediments indicate that for over a million years shallow seas, like the Hudson's Bay, spread in over New Hampshire. From time to time the earth's crust has slowly billowed up and down at the rate of a few inches a century, just as it does in places today. Sections of the crust tilted and spilled out the seas, only to have them return again to deposit another layer of seashore or seabottom sediments. Eventually these sediments compacted and cemented together into solid *sedimentary rocks.*

A great change took place in the old sediments during middle Paleozoic time (Devonian Period). The once-flat seabottom layers were arched up in great folds as though squeezed in a vise. In places the rocks broke and slid along great *faults* where identical layers are found to be displaced one from another by thousands of feet. During the contortion and folding the rocks were changed into more compact types called *metamorphic rocks.* Tiny grains of mud lost their identity and new crystals of mica, garnet, or other minerals formed. The whole process was aided tremendously by the heat furnished by molten rock material which began intruding from below as the layers broke and folded. The striking "crows-foot" pattern seen on some of the rocks of Mt. Washington are produced by these reformed minerals (sillimanite, staurolite, etc.) and later etched in relief by weathering. In this fashion the old sea sediments were changed to entirely different metamorphic rocks: schists, gneisses, and quartzites.

The *granite* of New Hampshire is still another story in the development of the rocks. There are large areas such as the Lake Winnipesaukee "basin" where such *igneous rocks,* once a molten liquid, are now exposed. Their coarse grain texture and large interlocking crystals show that they began as hot molten masses intruded from below and slowly congealed underground by cooling. There were four different great spasms when molten material was squeezed upward into the sea sediments. The first igneous rocks formed were greenish gray granites in the western part of the State. These are sheared and internally "ground up" by the folding which followed. As the folding began in mid-Paleozoic time, great elliptical domes of coarse pink granite came in near Rumney, Lebanon, Canaan, and elsewhere. Then into the tightly folded rocks one to twenty mile-long belts of gray granite and *porphyries* squeezed in. Although the bands lie parallel to the folds, they cut right across the edges of folded rocks so that they came after most of the folding. Finally, late in the Paleozoic Era (Mississippian Period) there was an invasion of igneous rocks producing round areas of *syenites* and related rocks. A remarkable point is that some of these intruded into great circular or crescentic cracks called *ring dikes.* The circular pattern of the Ossipee Mountains exhibit a perfect ring of syenite eight and a half miles in diameter—thought to be the only complete ring dike in the world. In the Belknap-Gunstock Range, the Moose-Copplecrown Mountains, and the Pliny-Crescent Ranges, several surges of molten material produced nesting groups of these crescents. Some of the molten invasion reached the surface and volcanoes were active. Evidence of this is exploded *breccias* or lavas like the blue-black *felsite* rocks of the central Ossipee Range, Moat Mountain, or Mt. Hale. Because they have tiny crystals, these igneous rocks cooled rapidly at the surface as they do in Hawaii today.

Put all together in the order in which they took place, the events which made the rocks of New Hampshire are:

About 300,000,000 to 400,000,000 years ago, in early and middle Paleozoic time, repeated inundations by shallow seas left layer upon layer of silt, sand, or limy mud;

About 300,000,000 years ago, in middle Paleozoic time, first

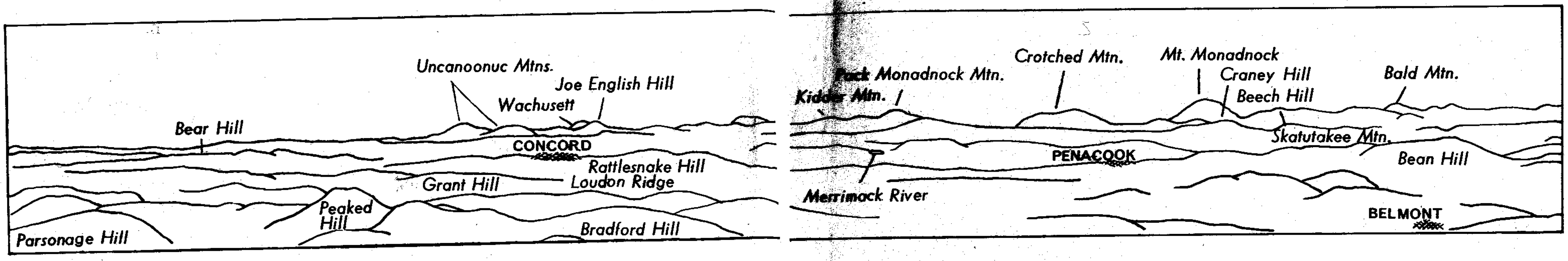


Figure 1. View southwest from Mt. Belknap showing the hills of central New Hampshire nearly all rising to one line or plane representing the level of an ancient erosion surface or "peneplain." Only a few more resistant peaks stick up above this former plain cut by erosion.

gray-green granites intruded up into the layers of the marine sediments;

From 250,000,000 to 300,000,000 years ago, layers of rock were intensely folded, faulted, and invaded by domes of pink granite all of which converted the sediments to metamorphic rocks;

From 200,000,000 to 250,000,000 years ago, in late Paleozoic time, long belts of gray granites intruded into the folded, faulted rocks and then great circular areas of syenite and ring dikes intruded and volcanoes were active at the surface.

HILLS AND VALLEYS TAKE FORM

Relics of Early Plains

The absence of any trace of sea deposition later than Paleozoic time in northern New England leads us to assume that through most of the last two hundred million years, New Hampshire was a land area undergoing erosion. These were the Mesozoic and Cenozoic Eras of time. Weathering processes were cracking, crumbling, and decaying the rock surfaces to form residual soils which rain, groundwater, and streams were slowly removing, partly by solution but largely as suspended mud.

During this vast span of time, the New Hampshire landscape undoubtedly changed several times from mountains to lowlands, although the proof of it is far less definite than in New Jersey and Pennsylvania or even in adjacent Massachusetts. In those states the complete leveling by erosion of the contorted rocks to a rolling low-

land, or *peneplain,* is inferred from surviving remnants which are now hilltops of nearly equal elevation. These hills could hardly happen to fall all at the same plane unless former erosion had bevelled off hard and soft folded layers nearly to one uniform level just a little above the sea (Figure 1). That peneplain in turn has been uplifted and dissected by valleys so that relatively few isolated masses of more resistant rock make up a simple sloping skyline. This upland is less and less uniform northward across New Hampshire and Vermont and the valleys and lowland areas carved out of it are deeper and more irregular. The peneplain cannot be convincingly seen over most of the State although detailed plotting of profiles like Figure 2 show that it really existed in southern and eastern New Hampshire. Probably it extended into the mountain areas as a system of broad shallow valleys. The White Mountains and some hilltops far from main streams withstood this planing by erosion and now rise above the hill-top upland. Such lone mountains are called *monadnocks* after the famous example in southern New Hampshire. Presumably this rolling hilly land was completed in middle Cenozoic time.

One of the puzzling old erosion surfaces is the "lawns" at 4,500 to 5,500 feet above present sea level on the higher White Mountains. The Alpine Garden, Bigelow's Lawn, and Boott Spur around Mt. Washington and Monticello Lawn high on Mt. Jefferson are striking flat shelves (Figure 3). The broad, rounded summit areas of the Carter-Moriah Range and the remarkable tableland on Mt. Katahdin in Maine seem to be relics of the same former land surface. Some believe these are the very last tiny flat remnants of a peneplain even older than the New England upland of Massachusetts and southeastern New Hampshire (perhaps early in the Cenozoic Era?).

Sooner or later each ancient surface levelled by erosion has been

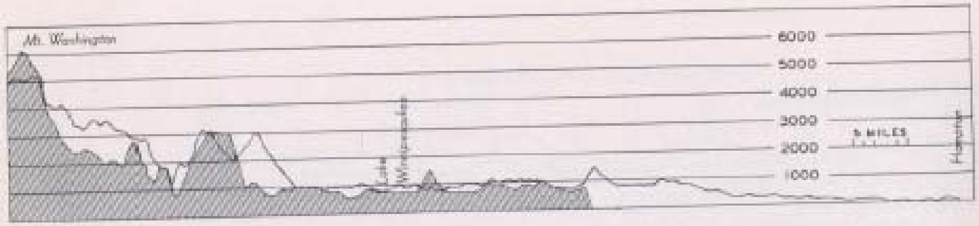


Figure 2. Profile of the New England peneplain from Mt. Washington southeastward to the sea along two lines (after Lobeck). This shows the upland rising from the sea to 1,000 feet at the base of the White Mountains, but broken by many residual masses or "monadnocks" which rise up above it.

uplifted by the restless earth's crust to become upland. As it rises high, rejuvenated streams etch valleys deeply into the folds of the metamorphic rocks and expose masses of buried granite. By projecting the ancient layers of sea sediments above the present land surface so as to reconstruct the folds which have been removed, it is estimated that at least one and in places perhaps several miles thickness of rock have been removed during the repeated cycles of erosion.

Mountains and Valleys Sculptured

Valleys etch out more deeply in areas where rock decays readily, or where natural joint cracks make excavation more rapid. A broad lowland was developed in the Winnipesaukee district on weak granite and down the Connecticut Valley on minutely split slates. Conversely, mountains are left generally on the toughest rocks; metamorphic schists preserve the high Presidential and Moosilauke Ranges, and solid granite "held up" the Sandwich and Franconia Ranges. Because rock structures in the Granite State are very irregular in their outlines, the mountains and ridges and valleys thus carved present a rather disorderly pattern.

When the glacial climate caused snowfields and mountain glaciers to form in New England not more than a million years ago, a hilly upland much like that of today surrounded the more rugged ranges of central New Hampshire. Slopes must have been cloaked with top soil and subsoil of local origin which graded downward through rotted rock into ledge. Main rivers like the Connecticut and Merrimack seem to have carved narrow troughs down through wide valley floors after the fashion of rejuvenated streams. These troughs, together with sharp "inner valleys" like those which score the west slopes of the

Figure 3. The high "lawns" around the cone of Mt. Washington. On the left is Bigelows Lawn, in the foreground is Boott Spur, and near the middle is Alpine Garden. Tuckerman Ravine and Huntington Ravine (right) appear as deep gashes cut back into Alpine Garden by former mountain glaciers. (Air photo by H. B. Washburn, Jr.)

Presidential Range, express a final uplift of land with respect to sea which may have taken place during the early phases of the Pleistocene Ice Age. Electrical sounding and deep borings to rock at Fifteen Mile Falls dam in 1935 revealed a gorge and wide floor buried by glacial drift. More recently, soundings through the glacial deposits by seismic instruments at Lowell, Massachusetts, have shown the old bedrock valley of the Merrimack somewhat to one side of the present valley but curving around under the city of Lowell.

The story of erosion pieced together from these sketchy records might sound something like this:

During most of the last 200,000,000 years since late Paleozoic time, valleys deepened, and grew broad repeatedly, occasionally developing into the low rolling surface of a peneplain;

Approximately 4,000,000 years ago in late Cenozoic time (or perhaps twice or half as far back) the last of the peneplains was tilted and carved into the hills of southern

New England and the broader valleys of the White Mountains;

Sometime between 500,000 and 1,000,000 years ago in the very latest Cenozoic time, the rivers began cutting inner valleys or gorges within the broader and old valleys. This continued until glaciers took over 100,000 or more years ago.

Glaciers Reshape Highest Valleys

Fortunately the invasion of the great ice sheet over all of New Hampshire during the latter part of the Pleistocene Epoch did not wipe out every scrap of evidence of glaciation during the first three quarters of that ice age. High on the slopes of the Presidential, Twin, and Moosilauke Ranges, there are spectacular glacial valleys with steep walls and broad floors. These valleys head in amphitheater-like walls 800 feet high known as *cirques* (Figure 4). Such landforms are unique to mountains with glaciers like the Alps.

It is quite certain that these local glaciers existed prior to the coming of the great ice sheet in New Hampshire because such extensive excavation must take far longer than the ten to twenty thousand years since continental glaciation. There is some question whether these same mountain glaciers reoccupied these same valleys after the ice sheet however. If they did reoccupy the old glacial valleys as recently as twenty thousand years ago, they were ineffectual, small glaciers because only questionable local deposits remain in Tuckerman Ravine while the markings of the continental ice sheet remain in these valleys untouched by local mountain glaciers.

At least ten glaciers carved the ravines on the Presidential Range.* Two or three glaciers enlarged valleys southeast of Twin Mountain. Possibly two or three short glaciers occupied basins north and west of Mt. Lafayette. One glacier widened Jobildunk Ravine on Mt. Moosilauke. The sidewalls and headwalls were steepened to craggy cliffs, and the floors were smoothed and rounded by the sandpapering action of rock fragments dragged down valley under the "stream" of ice century after century.

Glaciers might still eat back today were it not that summer temperatures average about ten degrees (F) too warm. Even now snow drifts so deeply in Tuckerman Ravine that a snow arch lasts

* Oakes Gulf, Gulf of Slides, Tuckerman Ravine, Huntington Ravine, Great Gulf, Jefferson Ravine, Madison Gulf, Bumpus Basin, King Ravine, and Ravine of Castles.

Figure 4. Great Gulf glacial valley on the north side of Mt. Washington. The steep cliffs at the head just below the Cog Railway are the walls of a cirque, 1,000 feet deep and 1,500 feet broad at the bottom. The ribbon-like mountain glacier filled the valley to the white line and scoured it out to a rounded "U" shape for 3 miles. (Air photo by H. B. Washburn, Jr.)

until midsummer. Very likely precipitation was heavier and snow drifted more deeply when glaciers existed in New Hampshire. In this connection all White Mountain glacial valleys lie either east or north of wide ridge areas above 4500 feet, but not one lies on the southwesterly slopes. This suggests that snow drifted from the southwest or west much as it does today. Those valleys, with broadest ridge areas to the south and west of them, supported the longest glaciers. The Great Gulf glacier swelled by three tributaries extended at least six miles from the headwall (Figure 4) but the average glacier was only one mile long. Furthermore, cirque basins developed fully one thousand feet lower down on shaded northerly slopes than on those southerly slopes which faced the warm sunlight.[1]

[1] Goldthwait, R. P. Geology of the Presidential Range. Bulletin No. 1, N. H. Academy of Science, 1940. 43 p.

COVERING BY AN ICE SHEET

Ice Growth and Decay

South of the Great Lakes region overlapping deposits show clearly that major ice sheets came into United States and wasted away four times at widely separated time intervals called glacial stages. Evidence of weathered and buried older glacial deposits in New Jersey and on Cape Cod imply an earlier glaciation in all of New England, but there is no clear proof of more than a single ice sheet over New Hampshire—that of the last or *Wisconsin Glacial Stage.* A few claim to see evidence that this one ice sheet did push across New Hampshire at two separate times beginning at least fifty-five thousand years ago.

In the early part of the Wisconsin Stage snowfields gathered on the Presidential Range and perhaps a few other high spots in the White Mountains enlarging the mountain glaciers already in existence. At the same time, snows accumulating in northeastern Canada compacted into a vast ice sheet of the type now covering Greenland. The ice moved perhaps only a few inches a day radially outward from snows in Eastern Canada toward a border of melting ice along the fringes of the ice sheet. We can imagine that it grew faster in Canada than it melted at its margin so that this ice sheet enlarged and finally coalesced with the valley glaciers in the higher White Mountains. The combined snow fields thickened until it all became one great ice mass all moving southward through notches and divides between the higher peaks in New Hampshire. The ice continued to thicken until it covered every mountain and valley in New Hampshire. Even on the highest summits there are some markings or deposits of the continental ice sheet.

Centuries later the climate ameliorated so that the ice sheet melted down at the surface faster than new snows gathered over Canada. The rough mountains and hills of New Hampshire acted to slow the ice sheet down to a standstill even while moderately thick. Stagnation of the ice, in the closing stages, seems to have come simultaneously over a wide marginal zone of the wasting ice sheet. While it melted back toward the north in a general way, it was thinning so fast over rough ground that it had no single boundary or front, much less one that can be traced across country by marginal moraines like those which cross the flat plains south of Great Lakes. Ice lingered in the valleys long after the hillsides had been uncovered, and floods of meltwater washed debris from the ice into ice-bound ponds and

passageways producing oddshaped mounds and terraces of bedded sand, gravel, and clay.

The events of this ice age complete the record of the Cenozoic Era nearly to the present time:

Commencing perhaps 180,000 years ago, and again more than 50,000 years ago, short mountain glaciers slowly scoured out the deep cirques and valleys of the higher White Mountains;

Between 40,000 and 60,000 years ago a great ice sheet gathered in Canada and grew southward overwhelming mountain glaciers in New Hampshire;

More than 20,000 years ago this ice sheet started to melt down and waste away;

Less than 14,000 years ago the last significant ice mass seems to have completely disappeared from New Hampshire (see page 48).

Glacial Scour

Moving in over New England from the St. Lawrence area, the ice scraped slowly across Vermont, New Hampshire, and Maine picking up first the frozen soil and rotten rock, and later excavating some of the fractured bedrock. This glacial *drift* material acted like giant sandpaper dragged across the surface. Where sand, silt, and clay filled the bottom ice, rock surfaces were rubbed until they had a smooth bright polish. Coarser rock fragments drawn across the rock floor cut straight scratches or *striations* in the direction of ice motion (Figure 5). The finest of these are tiny parallel lines etched faintly into hard, even-grained rocks like quartzite (Cube Mtn., Moose Mtn.) or narrow veins of resistant quartz. Rubbing a piece of wet moss or a soft pencil across the polished quartz surface reveals these fine lines. Coarser *grooves* several feet long and occasionally over an inch deep were cut by many stones dragged in the same path across soft rock. They are not so easily erased by weathering as are the fine striae, so only these large grooves are preserved on exposed ledges of igneous rocks like granite and syenite. Occasionally one can find a fresh ice-worn surface by removing thin drift from the bedrock.

Rarer marks of ice motion are the *crescentic markings* (Figure 5). They may be a foot or two wide and an inch or two deep. The most common type of marking is a nesting series of half-moon shaped fractures with horns pointing in the direction of ice motion. They were

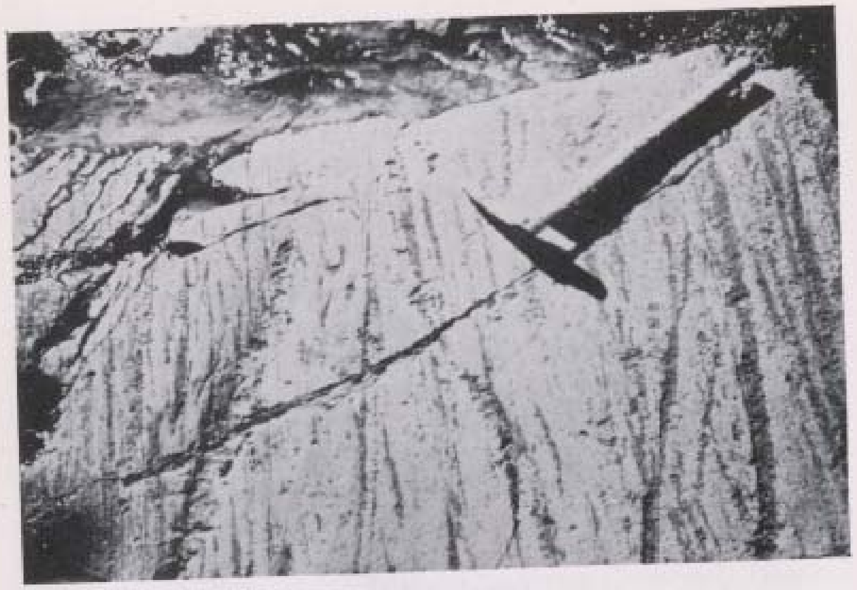


Figure 5. Striations and chattermarks made on ledges on Mt. Kearsarge by rocks dragged at the bottom of the ice sheet (Photo by D. H. Chapman).

formed on surfaces of granite and quartzite which slope against ice motion. Elsewhere boulders squeezed and chipped out semicircular slices of bedrock with horns in the opposite direction. They are most abundant on massive fine-grained rocks like the "volcanics" of Moat Mountain.

Sheepsbacks are knobs of bedrock that have been smoothed and rounded on the side up which the ice dragged, and steepened by plucking of cracked blocks on the lee side. The ideal well-scrubbed sheepsback is a few tens of feet long and elliptical in ground plan, but few achieved this shape on the irregularly fractured rocks of New Hampshire.

The glacial map of New Hampshire (in pocket) shows the direction of flow of the ice sheet over the State where striae or sheepsbacks have been measured at several hundred places. Some of the arrows represent several measurements of striae. It should be kept in mind, however, that nearly all of the striations were produced late in glaciation, because abrasion destroyed those made earlier. In a few localities striae of two distinct sets cross each other, so the two arrows shown indicate a shift in the direction of glacial flow. In the deepest valleys between mountain ranges (Crawford Notch, Pinkham Notch,

etc.) the direction of ice movement departs from the high level course as much as fifty degrees. This may represent a deflection of lower ice layers. However, it is likely that the movement of ice through these valleys continued for a little time after the highest ridges and summits had been uncovered by downwastage.

The highest ice-worn ledges and glacial grooves observed in New Hampshire are 5,700 feet above sea level on the old Crawford Path on Mt. Washington. They were first seen in 1841 by Prof. Edward Hitchcock, and have been visited ever since by geologists looking for proof that the great ice sheet actually covered this mountain range. Evidently severe frost action obliterated the grooves and broke up the ledges at high elevations on Mt. Washington (6,288 feet altitude) while the ice sheet was thinning down off the summits in late glacial time. But transported erratic stones and patches of glacial till as fresh as that in the valleys occur on the very top of the mountain and prove that even the top of Mt. Washington (Figure 25) was ice-covered for a time.[1]

The depth to which the glacier quarried out blocks of rock is learned from study of *sheet-joints* in granite. Sheet-joints are roughly horizontal fractures developed long before the Ice Age while rotting and erosion were removing the rocky cover from deep-seated granite masses. This removal allowed the rock to expand and crack in sheets parallel to the surface. Since the spacing of the sheet fractures increases with depth, the deeper the granite quarried, the thicker the sheets exposed. So by noting the thickness of sheets finally reached by the glacial excavation we may estimate how many feet the glacier lowered its floor. Statistical studies in Milford, N. H., and nearby granite areas in Chelmsford, Mass., have shown that the ice removed ten to fifteen feet of rock from the hills generally and tore out the lee side of some hills to a depth of one hundred feet.[2]

Another approach to the depth of the scour is the amount of material carried by the ice. Since the majority of the grains and stones moved no more than five miles from the ledges where they rotted or cracked off, we can "put back" the drift in imagination. The drift over New Hampshire averages not over thirty-two feet thick, based on a survey of wells reaching solid rock. Allowing for the fact

[1] Goldthwait, R. P. **Mount Washington in the Great Ice Age.** N. E. Naturalist, no. 5, p. 12-19. 1939.

[2] Jahns, R. H. **Glacial Erosion on Granite Hills.** Journal of Geology, vol. 51, no. 2, p. 81-94. In his article **Sheet Structure in Granites**, p. 71-98. 1943.

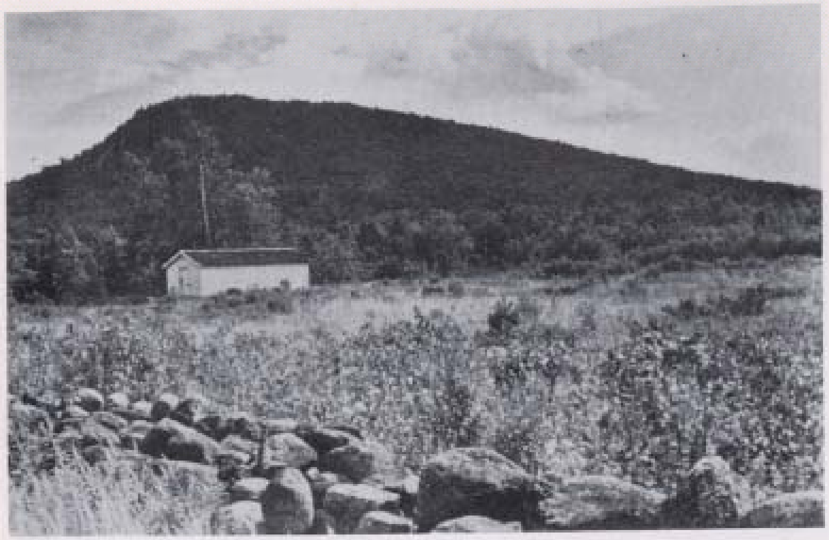


Figure 6. Rock drumlin hill in Wolfeboro. Whiteface Mtn. hills like this were shaped by the ice which rode over the hill from the right, rounded the top as if with giant sandpaper, and plucked boulders from the left lee slope to steepen cliffs. (Photo by R. P. Goldthwait.)

that drift is not packed so tightly as the solid rock, the excavation of rock by the ice averaged some twenty feet.*

So the glacier did little toward carving a new land surface beyond removing the old rotted rock and excavating in selected spots. Hills were somewhat roughened particularly on the lee sides. Locally at the southeast end of Lake Winnipesaukee, many hills composed of weak granite were scrubbed into streamlined form called *rock drumlins* (Figure 6). Scattered rock drumlins like Milliken Hill in Ossipee likewise are really large sheepsbacks.

On a few drainage divides, where high mountains deflected more of the creeping ice through a saddle, the ice movement was vigorous and the scour was concentrated. This is strikingly exhibited by deep cliff-walled *notches* like Carter Notch which forms a beautiful U-shaped skyline as seen from all up and down eastern New Hampshire (Figure 7). The depth and sharpness of Franconia, Crawford and Dixville Notches, some of the most scenic drives in New Hampshire, are largely ascribed to extra ice scour.

Glacial excavation concentrated also in some preglacial valleys

* This assumes that about as much drift was dragged into New Hampshire from the north as moved southward into Massachusetts or was washed into the oceans.

Figure 7. Carter Notch between Mt. Wildcat (right) and Carter Dome (left) in the White Mountains. This was deepened many tens of feet and rounded into a "U" shape by the continental ice sheet which rode through in the direction of this view. (Photo by G. Shorey).

where rocks were deeply rotted or closely jointed. Thus the floor of easily rotted granites under Lake Winnipesaukee happens to be eroded down approximately two hundred feet representing the depth of that lake basin surrounded by bedrock. Similar hollowing out produced some other rock-rimmed lakes even as high up as the Lakes of the Clouds at five thousand feet on the slopes of Mt. Washington.

Ice Deposited Dirt

Glacial *till* or "hardpan" forms a fairly continuous blanket over the bedrock. It is the type of drift which is composed of fragments of all sizes caught up from ledges by the moving ice, carried a few miles, and deposited as the ice moved or when the ice melted away.

The chief characteristics of till are: Extreme diversity in sizes of the grains which make it up, ranging from fine clay to silt, sand, pebbles, cobbles, and boulders; an utter lack of any real assortment or bedding; the angular or subangular shape of many of the fragments in contrast to the well-rounded pebbles and cobbles in stream or beach deposits; scraped and striated stones and boulders which may often be found; and, in addition, till in New Hampshire differs from till all through central United States because of its relative abundance of large stones derived from the chunky crystalline rocks right underneath.

The density of New Hampshire till is often high, averaging more than two times that of water. The more dense samples weigh 150 pounds a cubic foot when dry which is almost equal that of cement concrete. In a few places excavation by power shovels is difficult, but this high density also makes it ideal material for impervious cores of the flood control dams at Franklin Falls, Surry Mountain, and Webster. In spite of textbook statements to the contrary, its compactness is not due to its having been pressed down by the heavy ice sheet, but perhaps to the moisture content at the time of deposition of the till. Till excavated by shovels, brought by trucks, dumped loosely, and wetted with the right amount of water can be quickly rolled into a solid mass nearly as dense as the ice sheet made it.[1]

The deepest exposures of till in the State* have shown two distinct zones—"yellow till" over "blue till." The upper till, the only one seen in shallow roadside cuts, owes its yellowish-brown color to iron rust (mineral: limonite) especially the upper two feet. The lower till ten to thirty feet down is darker, bluish-gray, characteristically carries a little more clay, and is generally a bit more dense. The line of contact separating the two layers is sharp and in places is marked by a crusty concentration of yellow limonite. It corresponds closely to the slight change in density and to groundwater table which is commonly from ten to thirty feet down. Probably it denotes chemical change of iron-rich mineral fragments in the upper till which are rusted by alternate wetting and drying.

Glacial till was deposited beneath the ice sheet and wherever lower ice melted. In only a very few places can one tell what portion of the lower till at a given locality was laid down early under the ice and what portion was dropped down in the final stages when the glacier thinned. The upper portions of the ice contained relatively little debris, but in the lower portions the amount of debris was greater. Some of this lodged on rough bedrock irregularities as the dirty lower

[1] Goldthwait, L. **Glacial Till in New Hampshire.** Part 10, Mineral Resource Survey, Concord, N. H. State Planning & Development Commission, 1948. 11 p.

* In 1940-1941, in borrow pits for flood control dams at Franklin, Surry, and Webster; a roadcut at Westmoreland; an airport at West Lebanon; a town water supply line at Boscawen; and a high river bank below Bristol Dam.

Figure 8. Drumlin west of Halfmoon Lake, Barnstead. Unlike the rock drumlin (Figure 6) these hills are made of "hardpan" till deposited beneath the glacier and are shaped like the inverted bowl of a spoon. They are "streamlined" in the direction which the ice flowed. (Photo by J. W. Goldthwait.)

ice layers became clogged with debris. At the close of the Wisconsin Stage the ice thinned and finally ceased to move. The loose upper drift thawed out onto the surface of the thinning ice, and meltwater settling through it washed away some of its clay and silt. Thus the upper till generally contains less clay than the lower.

Drumlin Hills

New Hampshire bedrock hills show great variety of form, due to differences in size and shape of the rock masses within them, and their abilities to resist weathering and glacial erosion. But in portions of southern New Hampshire certain oval, streamlined hills of glacial till are numerous and markedly alike in shape and size. These hills, deposited and shaped by the ice sheet, are called *drumlins*. In form they resemble an inverted bowl of a teaspoon, with the long axis parallel to ice motion (Figure 8). They are seldom over three-quarters of a mile long, a half mile wide, or one hundred and fifty feet high. Water wells drilled at various levels on the slopes of these hills show the depth of till to average 66 feet.

As seen on the glacial map (in pocket) the several hundred drumlins occur in large clusters and there are few, if any, in the central and northern portions of the State. The Peterborough-Jaffrey-Rindge area has the most, while scattered groups occur around Walpole, Canterbury, Pittsfield, Barnstead, Rochester, and Kensington. This localization of clusters of drumlins may be due in part to favorable bedrock. Slaty schists in particular seem to have overloaded the ice locally with their clayey residual soil. Analyses of till from various New Hampshire localities show a generally higher clay content in the till composing drumlins. As this clayey till accumulated under the advancing ice, it was molded into oval streamlined form by the ice flow. In upper New York state it has been shown that even the pebbles in the till in drumlins sometimes lie in a preferred orientation showing the dragging and rolling by the moving ice.[1] Drumlins probably register the direction of ice motion for a longer interval of time than do striae or grooves, so they afford a better measure of the direction of flow of the ice.

Thickness of the Drift

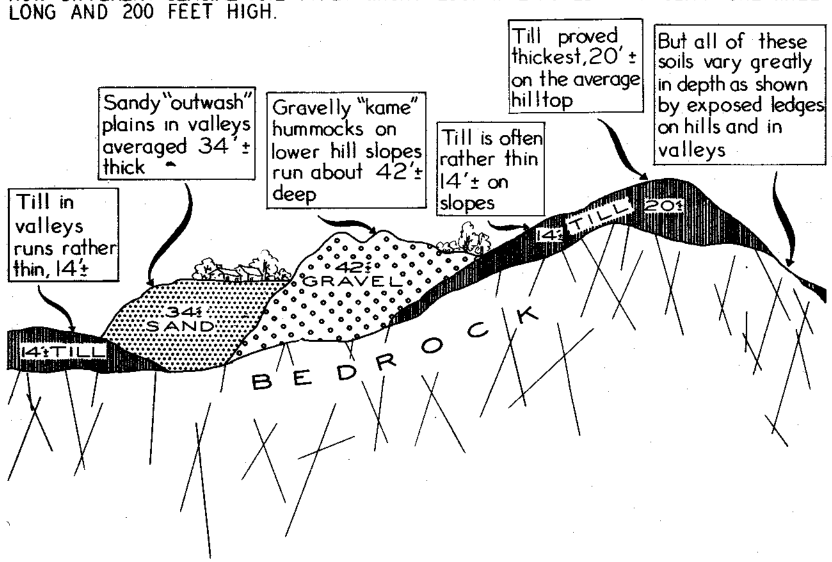
Although many roadcuts, railway cuts, and stream valleys in drift reach down to bedrock and give the impression that the overlying blanket of drift is shallow, a better measure of its thickness comes from some 1,600 records of drilled wells collected from all kinds of places over the State. Since most of these wells are distributed at random over the densely populated part of the State, records are very scarce in the White Mountain region and the north country.

The average depth of all drift is 32 feet, but this figure is deceptively high. This average is boosted by a handful of deep drift localities in valleys. The deepest known in 1951 was 395 feet in a well near Greenfield. Generally, the layered sand and gravel deposits of glacial rivers and pools have a mean depth of 37 feet (Figure 9). However, the outwash sands and lake bottom clays and silts of the Merrimack and Connecticut Valleys and their main branches are known from U. S. Engineers' records to reach thicknesses of over 100 feet.

Exposed ledges of bedrock seem to be most common on the mountains and on high hills so it is surprising to find that wells reveal

[1] Holmes, C. D. Till Fabric. Geol. Soc. Amer. Bull., vol. 52, no. 9, p. 1299-1354. 1941.

FIGURE 9. THE MOST COMMON DEPTHS OF VARIOUS SURFACE SOILS.
HOW DIFFERENT GLACIAL SOIL TYPES MIGHT LOOK IF EXPOSED IN A CLIFF ONE MILE LONG AND 200 FEET HIGH.



the thickest till (20 feet) on tops of the occupied hills and thinner till (14 feet) on irregular hillsides. Perhaps this shows that some of the till clotted onto the lower bedrock hills as ice motion slowed down.

Dispersion of Rocks

If you should count one hundred stones taken at random from most any gravel pit or road cut in New Hampshire, you would find many different kinds of rocks. Furthermore, most of the stones are like the bedrock beneath while the others show great variety of kinds of rock. Rocks which are different from the underlying bedrock are known as *erratics*.

Identifying single boulders as erratics from a known source has led geologists to map the scattering of boulders over the countryside. Such a fan-shaped area of dispersion is called a *boulder train*. Full and accurate mapping of a dispersion area requires field observation of all sizes of grains in the till. Indeed painstaking analysis of grains of sand size enables one to identify mineral particles as derived from unique rocks.[1] To map a dispersion area satisfactorily, (a) one has to use a rock or mineral type easily distinguishable from the other rocks or minerals of the region, and such types are not many; (b) there must be reasonable assurance that this type of rock crops out nowhere else within the dispersion area—a requirement not readily met where glacial drift conceals so much bedrock; (c) the source must be large enough to have fed plenty of fragments into the ice, for small sources twenty-five feet wide contribute little material to the drift beyond a hundred yards distance.

Again, if one is to make the fullest use of these scattered stones, he will take time to count the percentage of each distinct type, as has been done at several hundred places in New Hampshire. After gathering and plotting all the numerical scores on the map, the higher percentages of any type define the axis of the dispersion area, for this was the main direction of ice motion (Figure 10). On either side of the axis the lower percentages fan out 40 to 60 degrees due to changes in the direction of ice motion for short duration, or to slow-rolling turbulence and spreading within the ice as it crept along. Even though one takes the precaution to count only stones or grains within certain size limits, he will find in New England that the percentages are not altogether orderly in arrangement. This is due mostly to local variations in flow over a rough terrain and to the extent of fracturing of other bedrock crossed by the ice. Easily quarried types dilute the concentration of far-travelled erratics.

Red Hill in Moultonborough fed into the ice sheet millions of fragments of coarse black and white syenite which, though inclined to crumble into small stones, may be traced southeastward across the Winnipesaukee granite area for some twenty miles into Maine. It takes a sharp eye to distinguish pieces of this syenite from Winnipesaukee granite which dominates the drift here. Even at the source, at Red Hill, the percent of syenites is usually under twenty-five percent, but that gives added zest to the hunt for Red Hill erratics.

Hard fragments of blue felsite from Ossipee Mountains, abundant both in the drift deposits and among the loose fieldstones and boulders, were spread widely southeastward into Maine and can be followed to the seacoast at Wells. The wide rugged source, together with the strength of the rock, account for the great quantity of material and the length of the dispersion area. Unfortunately, the vast sandy plains around Ossipee Lake interfere with mapping its northern boundary.

[1] Goldthwait, J. W. **Mineral Composition of New Hampshire Sands. Part 9, Mineral Resource Survey.** Concord, N. H. State Planning & Development Com. 1948. 11 p.

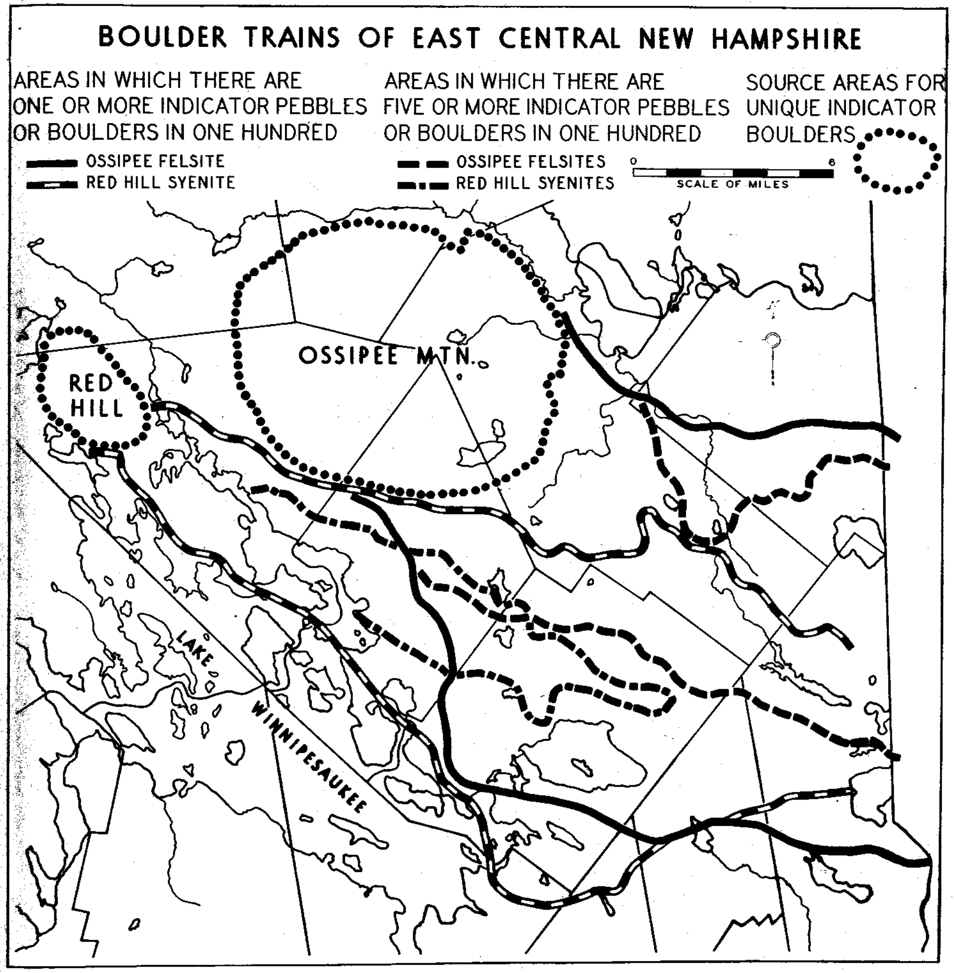


Figure 10. Details of the boulder trains scattered by the glacier from Red Hill in Moultonborough and from the Ossipee Mountains. Spread southeastward from each distinctive bedrock area (syenite at Red Hill and volcanics at Ossipee Mtn.) is an area in which one or more boulders in every hundred (1%) came from this bedrock source. Within this area is a region of still greater concentration where more than five (5%) in every hundred come from these parent ledges. Note how the ice scattered the boulders in one concentrated central direction, how the hills and valleys scattered boulders and altered the concentration or flow of ice.

Attempts to map dispersion of granite are less successful, because each type of New Hampshire granite reappears in a number of large areas scattered over the State. However, an elliptical area of coarse pink granite in Lebanon and Hanover (see page 7), measuring five miles by three, lies south and east of a broad mica schist area in Vermont. Flowing due south, the ice had acquired only enough granite fragments from ledges and hillsides to make a score of thirty-five percent in drift over the source area. But Lebanon granite boulders continue to make a good showing in stone walls of Plainfield, ten to twenty miles to the south. As you travel southeastward from any such source in New Hampshire, you will notice that the percentage of that kind of rock type diminishes rapidly. Twenty miles away from the source you will find generally that there is no more than one of them in a thousand rocks counted.

Erratic Boulders

It was formerly believed that erratics had been carried from their parent ledges by a prehistoric deluge of water and deposited when the flood receded, but it staggered the imagination to picture a deluge great enough to carry boulders weighing up to thousands of tons for distances of 30 or 40 miles and sometimes uphill or over mountains. Of course we now know that the ice was the transporting agent and that both large and small fragments rode along with equal ease.

The remarkably stony fields cleared by the New England forefathers, and the picturesque stonewalls today attest to the chunky boulder-making character of New Hampshire's crystalline rocks. This contrasts to the fine pulverizing character of the sedimentary rocks of central United States where boulders are rare and ninety percent of them come from far away.

Certain types of rock tended thus to furnish the largest blocks. The most common erratics in New Hampshire are granites and related syenites. This is probably due to the massive texture and the coarse jointing commonly found in such rock. Belts of coarse white-specked porphyry have produced numerous boulders in the Laconia-New Hampton and Danbury-Peterborough areas. Time during and since the last glaciation is so short that these easily rotted types are still fairly intact. Of course the most sparsely represented erratics are minutely fractured rock types such as slates. This explains the relative scarcity of erratics in the Connecticut Valley and in Coos County.

New Hampshire is noted also for its huge boulders such as the Madison Boulder, one of the largest erratics in the world. It measures 83 by 37 by 23 feet in biggest dimensions and probably weighs about 4,662 tons. This huge boulder apparently was brought by the ice sheet from ledges in Albany two miles north of its present resting place. At the time of Professor Hitchcock's first geological survey (1869 to

Figure 11. Bartlett Boulder. This granite erratic in Bartlett was carried by the glacier a short distance and dropped so that it perched on top of smaller boulders melted out of the ice. (Photo by J. W. Goldthwait.)

1878), the largest boulders known were those on the east side of Mt. Pawtuckaway in Nottingham. Some of the erratics, the so-called *perched boulders*, were left in most delicate positions by the ice. One of the most visited of these is the large Bartlett boulder located just off the state road a mile west of Bartlett station. It rests on top of four smaller boulders like an automobile on four wheels, and the whole group is perched on the crest of a small gravelly deposit (Figure 11).

The boulders which have always aroused the greatest curiosity are the *rocking stones* which the ice sheet placed in such a manner that one man can rock the heavy boulder back and forth. As far back as 1792 the early explorer Jeremy Belknap mentioned one in the town of Durham weighing perhaps 70 tons. Charles Hitchcock mentions several in the town of Marlow in 1871. In the 1830's notes were published about a 12 ton rocking stone in the woods at the south end of Ledyard Rocks in Hanover.[1] Others are known locally in various parts of the State.* Of the millions of boulders which the glacier left

[1] Potter, C. E. **Notice of a Rocking Stone.** Sillimans Jour. vol. 24, p. 185-186. 1833.

* Center Wolfeboro, N. H. in woods 200 yards north of the Cotton Valley Road; on Shirley Hill east of Uncanoonuc Mtn.; and on a hill about one mile west of Newport village.

in New Hampshire, only these few happened to be let down in an unsteady position onto the bedrock beneath and to have had their delicate balance undisturbed by frost, man, or earthquakes for the few thousand years since glaciation.

Rottenstone and Oddly Shaped Rocks

From the ancient subsoil the ice sheet acquired some oddly concave rocks and boulders known as *anvil rocks* or gnome rocks (Figure 12). Although discovered in many places and cherished as curiosities to decorate doorsteps and driveways, they are numerically very rare—perhaps only one such rock in a million fieldstones. Long chemical weathering rotted away the softer parts and left tough zones or dikes standing in relief as ribs. They were picked up by the glacier and incorporated in the heterogeneous till where they are found.[2] They are not meteorites as some have claimed because they do not have the fused outer crust of the highly heated "shooting star." Most of them are not boulders sandblasted into relief by vicious winds off the glacier as some would say, because the surfaces are rough, not sand-polished, and most of them are found protected by burial down in the till. However, as oddly-shaped relics of weathering before the Ice Age, they do deserve the attention they have always been given.

Many thousands of outcrops of bedrock in New Hampshire show fresh surfaces or only a slight crumbling and discoloration as a result of exposure since the Ice Age. Iron rust from groundwater has indeed gone down through joint cracks in some ledges staining their surfaces but it is hard to find places where softening and decay of the rock mass has reached depths of more than a fraction of an inch. Tough, polished and striated quartz veins rarely stand as much as an inch above easily rotted and "washed out" granite. Rotten rock by the barrelful or the truckload is scarce. Fifteen or twenty thousand years of postglacial weathering has hardly begun to make residual soil.

In sharp contrast to this general condition, deeply disintegrated and decomposed ledges have been located by geologists and engineers at forty or fifty small spots in the State. Among them are many different types of rock some of which are not types particularly susceptible to weathering. For example, coarse pink Conway granite and finer white Concord granite occur at Intervale and Gorham respectively in crumbled, soft masses ten to twenty feet thick (Figure 13). Patches

[2] Goldthwait, J. W. and Kruger, F. C. **Weathered Rock in and Under the Drift.** Geol. Soc. of Amer. Bull., vol. 49, p. 1183-1198. 1938.

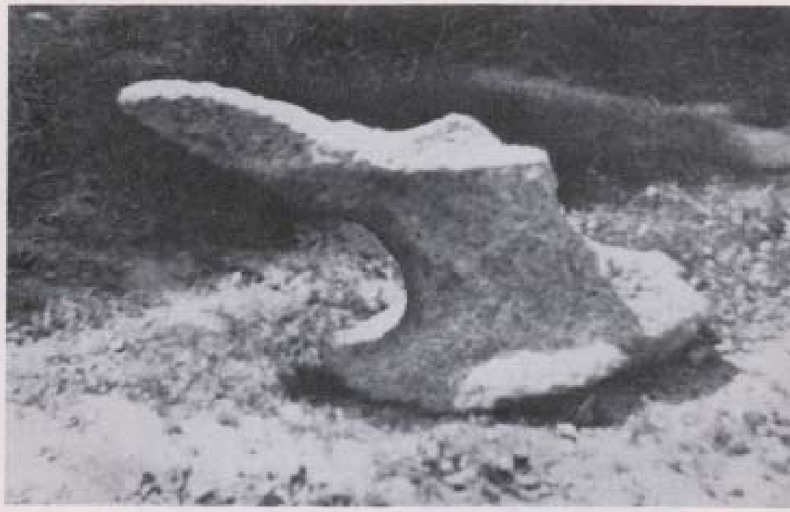


Figure 12. Gnome rocks in Ossipee. These oddly shaped rocks seen in farm yards are plowed from the glacial till in fields. Some look like goblins and others like anvils. Most of them were weathered into grotesque shapes by chemical rotting before the glacier picked them up. (Photo by J. W. Goldthwait.)

of preglacial weathered rock have been recognized elsewhere in New England.[1] One may reasonably conclude that these rare spots of rotten rock are vestiges of the preglacial mantle of altered rock which the ice sheet failed to pick up and carry off.

This view gets strong support from the discovery of six localities where rotten bedrock is covered by fresh glacial till.* Some crumbled rock and residual boulders appear in the base of the till sheet, partly torn from the rotted ledges but left within a few feet of their place of origin. Side by side with these are fresh boulders of the same type of rock quarried by the ice from more solid ledges. Oddly enough, at all six localities one may see narrow dikes of till matrix which squeezed far down into weathered joint cracks of the rotted ledge. The injection of till shows that the greater part of the weathering dates back before glaciation.

These *clastic dikes* show how strong was the downward pressure of the glacier and how plastic was the juicy till beneath it. They sug-

[1] Leavitt, H. W. and Perkins, E. H. **Glacial Geology of Maine.** Bull. 30, Maine Technol. Exper. Sta., vol. 2, p. 13-14, 1935.
Flint, R. F. **The Glacial Geology of Connecticut.** Bull. 47, Conn. Geol. and Nat. Hist. Survey, p. 49-51. 1930.

* 2½ miles west of Gorham in railroad cut, or just north of Rattlesnake Mtn. in Sandwich, 3 miles west of Keene, in Pawtuckaway Park near the Deerfield-Nottingham line, or just south of Kearsarge village in Conway, or in excavations under the U. N. H. athletic field at Durham.

Figure 13. Clastic dikes of glacial till along a railroad cut three miles west of Gorham. The dark gray till was squeezed by the glacier into cracks in the rotten light gray granite. The axe is two feet high. (Photo by J. W. Goldthwait.)

gest what geologists have predicted for two decades, namely that the bottom of a great ice sheet is at or near the melting temperature.

Since the ice scalped off this rotten rind of bedrock in all except these localities, the till generally must contain a large proportion of grains already weathered before glaciation. These weathered clay and iron minerals are recognizable under the microscope. A study in Minnesota showed that they constitute 40% of the till[1] and there is no reason to believe the proportion is much different in New Hampshire.

[1] Kruger, F. C. **Study of Certain Drifts in Minnesota.** Amer. Jour. Sci. 5th Ser. vol. 34, no. 203, p. 345-363. 1937.

THE ICE MELTS AWAY

Meltwater Channels

As the surface of the ice sheet wasted down so that mountains and hilltops emerged through it making island *nunataks,* new processes of sculpture came into action and new deposits began to form. The ice thinned unevenly against the hillsides releasing streams of meltwater. At places these torrents escaped across ridges and spurs cutting *channels* in till or solid bedrock. Each channel is a distinct, small trough one hundred to a thousand feet long and up to fifty feet deep between oversteepened walls. Often the floor is littered with water-rounded cobbles.

Most of the ice age channels did not develop until the ice sheet had shrunken down to sprawling masses of dirty ice in the lower valleys, because recognizable channels are surprisingly scarce at high elevations. The highest is a short hollow with rounded waterworn cobbles across the crest of the Presidential Range in Edmunds Col. Of course some high channels were erased by slumping and sliding due to frost action, and furthermore, according to the law of averages, few streams would be likely to impinge upon these few early nunataks. Had a steep ice front melted back systematically northward, as was commonly believed three decades ago, there would be general scattering of channels even at high altitudes.

Perhaps a hundred meltwater channels are found in groups of three to ten on the lower valley sides. Several of the finest channels thirty feet deep fall obliquely across high hillside pastures, on till at Jefferson Highlands. These seem to have been cut by streams flowing eastward along the northern edge of ice occupying the whole broad Israel River Valley. On the south side of this same valley on deeply wooded slopes, there are channels at matching levels cut in bedrock. In the Wolfeboro-Winnipesaukee area several meltwater channels can be traced across ridges of till for a few hundred or a thousand feet.* Each one is too large, too high, or too near the watershed divides to be the work of modern streams, and they tend also to run along the slope rather than down it (Figure 14).

These channels slope in every compass direction showing that the wasting ice masses were indeed irregular. Those around the east side

* At 1,000 feet attitude on the west side of Cotton Mountain; near Hersey Cemetery west of Bennett Hill; in Lakeport at Valley St. and on the hillside east of it; in Gilford (Figure 15); two miles north of Brookfield Village; on the north slope of Tumbledown-Dick Mtn. near Lake Wentworth (Wolfeboro); around the north side of a hill just south of Rust Pond.

Figure 14. Channel carved by glacial meltwaters into a hillside, Stewartstown. As in many situations in New Hampshire, the last decaying ice filled valleys, and floods of meltwater coursing off the ice and back onto it eroded short curving channels far too high to be the work of any present day stream. (Photo by J. W. Goldthwait.)

of a hill on the Wildcat Reservation in Jackson incline gently northward; those around the northwest side of Hubbard Hill in Charleston slope westward; others on the north side of Belknap Mountains in Gilford flowed eastward (Figure 15), and a majority sloped southward as on the east side of Plot Hill in Lyme. The ice thinned unevenly, and its surfaces drained off in assorted directions but mostly southward toward the furthest limit of ice push.

There are many other traces of flowing meltwater. Most of these channels are associated with gravelly stream depcsits that collected on and against the ragged edge of the ice. The gravel knolls stretching east of Jefferson Highlands to Bowman are an example. At the end of one channel at Jefferson Highlands and at odd places on high hillside ledges there are smooth cup-shaped hollows worn by water.

Potholes Drilled by Glacial Streams

Among the strange relics of the Glacial Period in New Hampshire waterworn *potholes* perhaps deserve first place. They are smooth cylindrical or spherical holes drilled down into solid rock by eddying streams. Some potholes, usually only a few inches or a foot in diameter, are drilled by whirling gravel into ledges where modern streams plunge and swirl at fixed points. Fine examples are seen at Upper

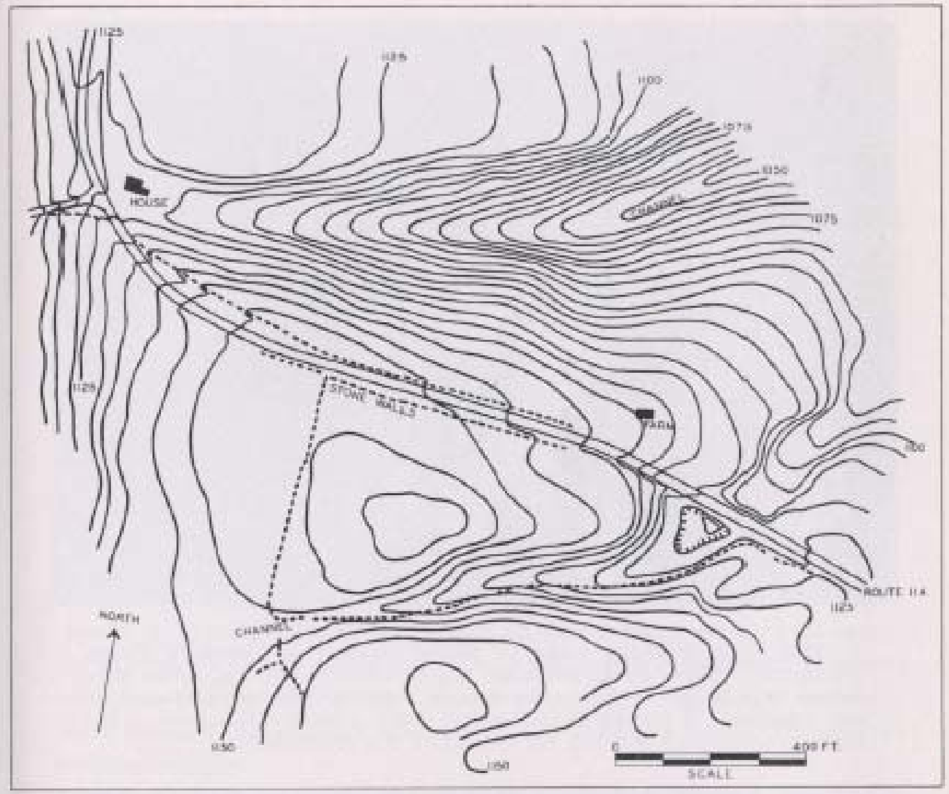


Figure 15. Two channels cut by glacial meltwaters across the watershed, east part of Gilford. Each contour shows points of equal elevation and adjacent contours show elevations five feet apart.

Ammonoosuc Falls in Bretton Woods. But most of the larger potholes in stream beds in New Hampshire appear to date from the Ice Age when meltwater flowed down these defiles with greater volume than that supplied by rain and winter snows today. These reach giant size up to twenty or twenty-five feet across at Lost River and the Basin.[1] At one stage the wasting ice in Benton poured volumes of meltwater through Kinsman Notch. Even more definitely of glacial origin are hundreds of potholes mysteriously located on rocky hilltops and hillsides above any definable river course past or present.*

[1] McNair, A. H. **The Geologic Story of Franconia Notch and the Flume.** Concord, N. H. State Planning & Development Commission, 1949. 14 p.
.... **The Geology Story of Kinsman Notch and Lost River.** Concord, N. H. State Planning & Development Commission, 1949. 14 p.

* Indeed it has been debated for some years whether fine small potholes on the Ridge of Caps of the Presidential Range were made where they are found 3,760 feet above sea level, or brought up on an erratic.

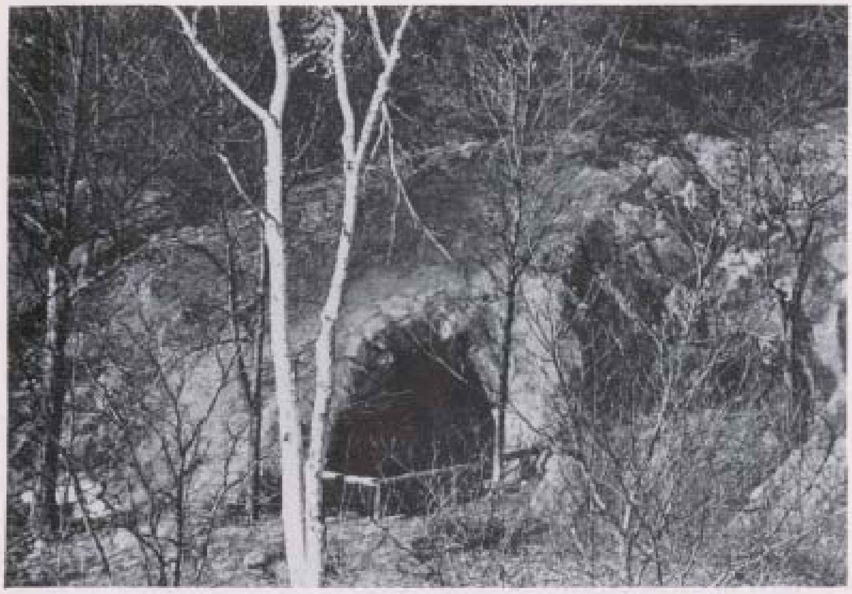


Figure 16. Potholes made by glacial streams at Plummers Ledge, Wentworth. These great cylindrical pits three to fifteen feet across were drilled 10 or 20 feet deep into the slope of a granite ledge by whirling sand and pebbles in a torrent of meltwater. Only a glacier filling the valley would produce such currents 100 feet above the valley floor.

Louis Agassiz and other geologists of the last century usually accounted for the isolated potholes, now high and dry, by plunging of meltwater through vertical cracks or crevasses in the glacial ice. These enlarged into well-shaped *moulins* or mills where gyrating boulders, cobbles, and gravel churned with intense cutting power. Even so, it is hard to see how either moving or stagnant ice could hold in position a plunging torrent long enough to drill a cylindrical hole ten or more feet deep in rock. The three giant potholes at Plummer's Ledge in Wentworth (Figure 16) are the most puzzling of any for they are not only very large and very deep (to 20 feet, enclosed depth) but they were cut straight down into a ledge on its forty-five degree side slope. Perhaps it is more logical to picture streams of meltwater draining the uneven surface of dirty melting ice, and only here and there impinging on exposed spurs of rock sufficiently long to drill the holes.

It has long been a pastime to search in potholes for elliptical and spherical stones and boulders. Some of them are as round as cannon-balls like those exhibited at Glacial Park in Thornton where

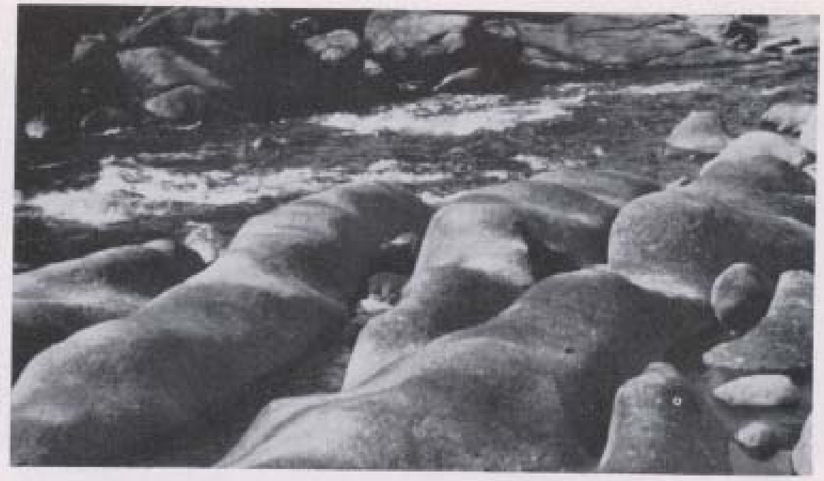


Figure 17. The Mummies at North Woodstock. These smooth grooves and ridges were cut in solid granite by swiftly moving water and sand. (Photo by J. W. Goldthwait.)

dozens of glacial potholes have been exhumed along an ancient course right next to the Mill Brook. To grind a single pothole, hundreds of such stones probably took turns dropping in, spinning, becoming worn rounder and smaller until they swirled out of the cavity or were reduced to sand.

Related to potholes and sometimes near them are cup-shaped waterworn surfaces of a great variety of shapes and grouping, like Agassiz Basin in Woodstock and the Sculptured Rocks of Hebron. They almost certainly owe their existence to the floods of late glacial time, although heavy rains and spring freshets still roll cobbles and boulders around in them. At North Woodstock "The Mummies" were carved out of mica schist where the river has been sweeping heavy rolling gravel and boulders diagonally across the rock structure (Figure 17).

Glacial Stream Deposits

Dirt which was once carried by meltwater becomes distinguished from till by its sorting according to grainsize. That is, all of the fragments in one layer may be of silt size, or all the grains are of sand and gravel sizes, and clay grains are washed away. The coarse grains rolling and skipping down a stream channel come to rest first by settling wherever there is slack water. Thus they fall in layers a few inches or feet thick lying one upon another. Ordinary streams make

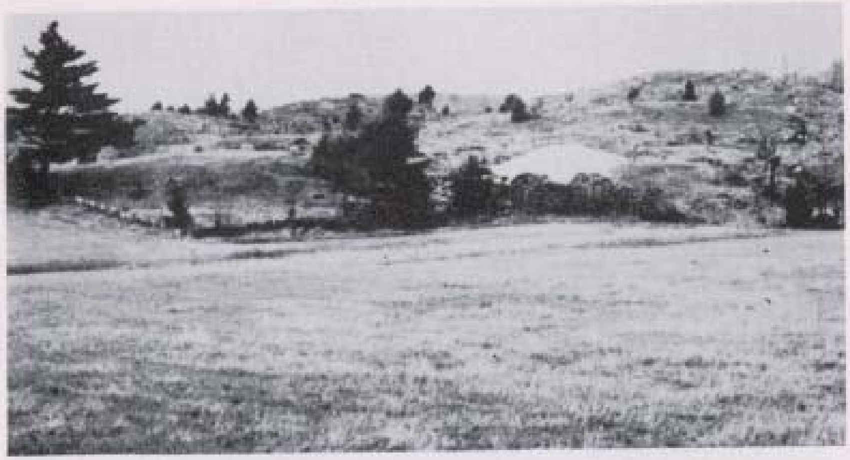


Figure 18. Kames at West Canaan. These are hummocks made of layers of sand now exposed in small gravel banks. The layers were poured by meltwater into pits in the decaying ice sheet as the last ice lay against this hillside.

such deposits. However, the flooding and ebbing meltwaters at the edge of the ice often lead to very coarse cobbly gravel layers. These gravels were poured into irregularly shaped pools surrounded by the rotting ice. When the retaining ice melted away, the deposit on the pool bottom remained as an irregular mound or hummock called a *kame*.

If the scarcity of meltwater channels at high levels is surprising in a region which ice once completely covered, the same can be said of the very limited high occurrence of these ice-marginal kames. They are abundant only in lower valleys. Everywhere, as the ice wasted away, the loose drift either packed down and came to rest on slopes as unsorted till, or, carried by streams, it was washed and rewashed on ice at lower and lower levels, coming to final rest as sandy gravel on ground when only the valleys held patches of ice (Figure 18).

Wherever the sands and gravels settled in an area a hundred or more feet broad on the hillside against ragged ice, a flat-topped *kame terrace* was formed ten to a hundred feet above the ice-covered valley floor. Just as the deposit in the bottom of a small pool surrounded by ice forms a kame, so the broader gravel deposit forms a flat-topped bench or gravel step along the side of a valley.

Where the water flowed through chains of pools, between an ice tongue and the valley sides, meltwater built many kame terraces with typical *delta structure* (Figure 19), but never the delta form. These

Figure 19. Structure of the layers of sand in a delta at Lancaster. Water coming from the right swept sand onto the inclined "foreset" beds, building them out into a former lake on the left. It covered the top with horizontal "topset" gravel beds just about at the surface of the glacial lake. (Photo by J. W. Goldthwait.)

pools were always filled up completely so that the bedded gravels and sands rested against the ice on one side and sloping ground on the other.

Long mistaken for deltas or remnants of deltas,[1] these flat-topped stratified deposits are still thought by some to register levels of extinct glacial lakes, but it is now generally agreed that most of them formed when the valleys were occupied by thin honeycombed ice rather than open water. According to this view, broad "Glacial Lakes Winnipesaukee and Contoocook" never existed. However, the Merrimack Valley below Franklin contains a widespread series of bedded lake-bottom sediments so it is an exception, and similar silts and clays reach all the way up the Connecticut River Valley from Hartford, Connecticut to Littleton, New Hampshire, justifying the names glacial "Lake Hitchcock" and "Lake Upham."

Some of the meltwater flowing on ragged, honeycombed ice found passageways within and at the base of the last rotten ice, because sorted gravels and sands pouring through tunnels and canyons settled to the bottom of the slack parts of each water course. Now that

[1] Goldthwait, J. W. The Geology of New Hampshire. N. H. Acad. Sci. Handbook No. 1, p. 42. 1925.

the ice is gone these are left as sinuous *esker* ridges along the valley floor. Standing ten to a hundred feet high with a sharply rounded crest and a base three or more times as broad, each esker ridge is often a mile long and, together with its neighbors end to end up and down the valley, it marks the long course of subglacial meltwaters. In general the more stony and cobbly material was found near the top representing the closing surges of meltwater through the ice gorge. One prominent esker chain stretches 14 miles from Lyme to West Lebanon down the Connecticut River Valley. Tributary meltwaters joined the main ice tunnel in places as shown by attaching esker ridges from neighboring valleys. The fine high esker along Pine River next to Route 16 in Ossipee is joined by a chain of ridges from Ossipee Corner (Figure 20).

The Pine River esker exhibits another interesting feature. This ice-bound river flowed uphill! The same striking blue-black felsite rocks, which showed glacial dispersion of drift from the Ossipee Mountains, are found in the tributary esker and in the main esker, but only southward from where that tributary joins it. Therefore the meltwaters were flowing south in this tube, but it so happens that the south end of the esker near Pine River Pond is more than one hundred feet higher than the northern part of the esker near Ossipee Lake. Similarly southward carried stones in the esker between Fabyans and Crawford Notch were forced in an ice tube many tens of feet uphill.

All of the gravelly kames, terraces, and eskers of glacial streams mapped for the Highway Department are shown in red on the map of *Surficial Geology of New Hampshire* (in pocket). Meltwater poured quantities of sand and stones through every available opening, shifting its paths as often as it discovered new lines of escape. Near Farmington, powerful glacial rivers laid a deep network of cobby gravel deposits within ice walls which now stand up as great esker ridges. From there kame terraces extend down Cocheco Valley to the wide flat sandplains north of Rochester. Still farther inland, eskers and kame terraces run down the Soucook Valley for 23 miles between Belmont and Loudon. In the Merrimack Valley great kame ridges and eskers formed near Manchester while ice occupied the valley. Later flatter and more sandy outwash deposits were spread around and against them when glacial streams were free to shift from one side of the valley to the other.

Outwash Sandplains

Some meltwaters reached open valleys where little ice remained. With little ice to restrict it, the waters spread out first right and then left depositing more or less horizontal layers of sorted sand which slowly filled the broad low area from side to side with an *outwash plain*. Just north of Dover the sandplain is 9 miles long by 2 miles wide. "Dark Plains" east of Concord have been trimmed back by the Merrimack River exposing sandy layers 70 feet deep. These plains make ideal airports* because the surface is broad and nearly flat, and gravel standing ten to a hundred feet above the adjacent valley

* Airports on outwash plains are found at: Claremont, Concord, Hinsdale, Hooksett, Lebanon, Manchester, Milan, Nashua (2), North Conway, North Hampton, Penacook, Somersworth, Twin Mtn., and Whitefield.

Figure 20. Esker ridge along Pine River in Ossipee. The ridge is the deposit of water-laid sand and gravel from one glacial stream flowing in a tube in the decaying ice sheet. Only an ice tunnel will hold the water along such a crooked channel running uphill to pile the layers up over 100 feet high. Sand and gravel from the pit in the center were used for the concrete road at the left.

floor drains very well. In places the plains lay against some ragged ice and have an irregular boundary on one side. Small lingering ice masses were buried by the flooding sands; then centuries later, when the ice melted out from beneath, the sands caved in leaving an irregular or circular depression entirely surrounded by sandplain. Many such *kettle holes* contain small ponds like Great Pond in Kingston or Willand Pond in Somersworth or White Lake at Tamworth. All of the sandplains large and small are shown in yellow on the map, *Surficial Geology of New Hampshire* (in pocket).

Sandplains are most conspicuous in southeastern New Hampshire near the seacoast. Broad, poorly defined outwash deposits of large size together with kames and terraces, appear to be concentrated over the coastal lowland in parallel belts several miles apart running northwest-southeast. One cannot tell whether many of these formed at the same time or whether they were built one by one more or less in sequence from the southeast toward the northwest. But detailed mapping of them makes it clear that they do not line up parallel to the coast. Nowhere do they mark halts of a retreating "ice front" melting back toward the northwest as was once supposed.[1] Instead the ice seems to have uncovered this lowland almost simultaneously by vertical downwastage. Since these washplains, kame terraces, and kames reach lower and lower elevations toward the southeast, they were formerly interpreted as delta-like deposits marking the glacial sealevel tilted today so it is no longer horizontal. The view now is that the seaward slant of the kame system is due at least partly to the gradient of ice-bound rivers that built them.

[1] Keith, A. and Katz, F. J. **The Newington Moraine. U. S. Geological Survey Prof. Paper 108, p. 11-29. 1917.**

Glacial Drainage Courses

Ice still occupied the broad basin of Lake Winnipesaukee while marginal streams built a broken line of gravelly kames and kame terraces along the West Alton shore. The level of their tops declines steadily toward Alton Bay, and leads to wide sandy outwash plains in Alton Village and New Durham. Thus, while the Cocheco Valley became free of ice near the broad sandplain, there are no clear signs of open water above the present Lake Winnipesaukee, and no outlet channel leading toward Cocheco River. Off to the southwest of Lake Winnipesaukee on hillsides of Gilford and Lakeport, a few marginal drainage channels descend toward Laconia, and one deep channel in particular runs through Lakeport along Valley Street. The old idea that these were early spillways of a "Glacial Lake Winnipesaukee" dammed by a receding ice "front" is now discarded, because there are no lakeshore deposits at one consistent level and no continuous lakefloor mud deposits. Instead the channels were cut by meltwater escaping at lower and lower levels as the ice wasted downward against enclosing hillsides. Associated with them are oddly shaped *crevasse fillings*, particularly in the northeast part of Laconia where large volumes of fine sand and silt were washed into narrow cracks in the ice. Convincing proof that channels like these were not cut by water issuing from a great lake is found in the short but deep channel east of Hersey Cemetery in Wolfeboro. This was cut by a stream flowing toward the Winnipesaukee lowland instead of out of it, and it must have issued from the thinning glacier ice.

In the Contoocook Valley scattered deposits with flat tops and delta structure, but without delta form, were long supposed to mark "Glacial Lake Contoocook."[1] It now seems clear that no deep lake occupied this valley but a lingering ice mass rested against its sides catching meltwater and sand in pockets high above the valley floor. So, the southward descent of the kame levels from Hillsborough to Bennington indicates the original southward discharge of a marginal drainage system. There is no outlet at the south end of this Contoocook area, but only the usual eskers and outwash plains. At the northeast corner of the Contoocook Valley in Hopkinton, where a "retreating ice front" would have opened a later outlet, are kames, eskers and outwash plains but no river channels. The ice, wasting down into the Contoocook Valley, doubtless had a southward slanting

[1] **Upham, W. Modified Drift Along the Contoocook River. In his chapter, Modified Drift in New Hampshire, p. 103-120, vol. 3, part 3, Geology of New Hampshire by C. H. Hitchcock. 1878.**

surface which receded northward as it melted, but it seems to have thinned downward more than backward without forming a wide sheet of open water at any time.[1]

In many other valleys the same southward or eastward flow of meltwaters is evident: Upper Connecticut, Baker, Smith, Warner, Piscataqua, Lamprey, and Souhegan Rivers. Each one has kames or terraces in descending levels seaward. Perhaps some of the esker chains described earlier in the northern and western parts of the State (upper Ammonoosuc Valley, Connecticut Valley south from Lyme, Madison, Pine River) were being built at the same time as great sand plains were being spread in the southeastern lowlands. In valleys which today flow northwestward (Israel River, Upper Ammonoosuc River, Upper Mascoma River) there is evidence in the stones of an esker, or the slope of a channel, or in the decline of kame terraces that glacial waters flowed opposite to those today.

Marine Clays

When the margin of the ice sheet began to thin down and melt back from the coast of southeastern New Hampshire, the land stood somewhat lower than it does today, because the weight of the ice sheet actually depressed the earth's crust. Evidence from glacial lakes suggests that southern New England was only a few tens of feet lower and northern New England was down a few hundred feet (Page 48). However, the sea also stood at least three hundred feet lower all over the world because ice sheets stored up many millions of cubic miles of water. Thus, when the ice first wasted away exposing southern New England, more land was exposed above salt water than there is today. This is shown by the broad outwash plains from coastal Maine through New Hampshire to Rhode Island which slope ever so gently southward under the present sea as though reaching down to a lower sea level.

Glacial meltwater poured back into the sea as the ice melted and shortly the seas swelled so that they rose faster than the land surface came up. This drowned some exposed coastal lands and sandplains. The sea continued to come in not only to the present seashore but ten to fifty miles further in over what is now southern Maine and southeastern New Hampshire.

Deposits of typical blue sea clay, stiff and yet plastic have been opened up for the brickyards of Rochester, Gonic, Epping, Exeter,

[1] Goldthwait, J. W. The Uncovering of New Hampshire by the Last Ice Sheet. Amer. Jour. Sci., vol. 36, p. 345-372. 1938.

and East Kingston. Rarely, actual sea shells of cold arctic shellfish have been found.* The clays occupy somewhat lower ground near the outwash sands and gravels but generally lapping onto them showing that the sea invaded as the last glacial meltwaters subsided. At Portsmouth and Rochester interbedded clay and gravel twisted by ice thrust or by collapse of supporting ice walls shows that the sea rested against irregular ice. Although the clays form a rather continuous sheet in southern Maine and Massachusetts, they are in discontinuous patches in much of New Hampshire. It is likely that this drowning by the sea came so promptly after the ice melted, that thin ice masses may still have occupied some low ground and all of interior New Hampshire while clay was being deposited.

To some extent the wasting ice masses may have prevented waves and shore currents from washing up good sea beaches or cutting distinct seacliffs or dumlin islands and headlands in New Hampshire. Before good contour maps were available and before many gravel pits had been opened in this area, it required only a fair imagination to see old sea beaches in the level crestlines of sandy and gravelly ridges, or old wave-cut benches and cliffs where island-like drumlins appeared over-steepened and bordered by gravelly terraces. A few of them, indeed, may still be considered true shore features—a "hooked spit" behind the Stratham Hill drumlin and beachlike ridges at Rollins Hill—but other "beaches" and "terraces" in this area were definitely built into pools or passageways in the ice thinning around a hill. They are on the "exposed" seaward sides of hills where no spit would form, and the beds are too bouldery and steeply dipping. Surveys and plottings of these "marine" watermarks showed the "Marine plane" slanting south from near two hundred feet at Rochester to one hundred feet at Amesbury and Newburyport. But the only real proof of marine origin is seen in clays at lower levels.

Recently it has been demonstrated that the marine clays overlapping into low outwash and fingering up low valleys occur on higher and higher land as one traces them inland into New Hampshire or Maine. In coastal towns of Portsmouth and Rye clays pinch out on hillsides above 70 feet. Inland near Gonic they mantle higher slopes up to 200 feet. This is partly explained by wave wash moving the clay lower as the sea receded to its present position and, as is well shown elsewhere from glacial lakes the whole of New England was

* Many fossils have been found in the clays in Maine. See Leavitt, H. W., and Perkins, E. H. Glacial Geology of Maine, Bull. 30, Maine Tech. Exp. Sta., vol. II, p. 204-207. 1935.

tilted in the broad warping up of the land after the ice disappeared and the sea clays had been laid down. In any case the sea was evicted from southeastern New Hampshire and the land emerged to something like its present position.

Ice Dammed Lakes

The valleys of interior New Hampshire were a little too high, even before the surface tilted back up, to be flooded with clays by the rising sea. The irregular wasting masses of ice in most of them did not favor wide open lakes or fine deposits. But in three exceptional valleys—Connecticut, Ashuelot, and Merrimack—there are fine silts and clays. Thick deposits of well-sorted silt and clay particles in these valleys must have settled out in very quiet water, because fine particles settle only in still bays or lakes. Originally these sediments seem to have extended without a break up the Connecticut Valley to near St. Johnsbury, Vermont, locally forming a broad, smooth floor that is now deeply trenched by the river—as in the Hanover plains.

The peculiar layering of these deposits denotes a yearly accumulation known as *varves.* In summer, when melting was in progress and glacial rivers were flooded, sediment was rapidly swept into the lakes, and all the fine sand and silt as well as some of the clay, settled promptly to the bottom. The remainder of the fine clay settled in quiet water covered with ice during the following winter. This made layers of silt or sand in summer which grade upward into thin seams of clay in winter (Figure 21). It follows from this that a section of freshwater clays if undisturbed by sliding or glacial readvance, enables us to count the exact number of years over which the deposit formed.

In old brickyards in Keene some four hundred layers of varved clays and silts indicate that quiet water of a lake endured there at least that long, but the area of the lake itself is not known. Three or four hundred layers are found at many places in the Merrimack and Connecticut Valleys; and in a few places over a thousand have been counted.

In any one clay bank the varves differ from one another in thickness. A thick varve, as a rule, marks a year when the melting season was long or intense, whereas a thin varve marks a year of cooler temperature and less melting. Sunshine rather than rainfall is believed to have controlled melting . Since yearly or seasonal variations of climate are fairly uniform over areas the size of New England, the varves within that area may be expected to show similar variations.

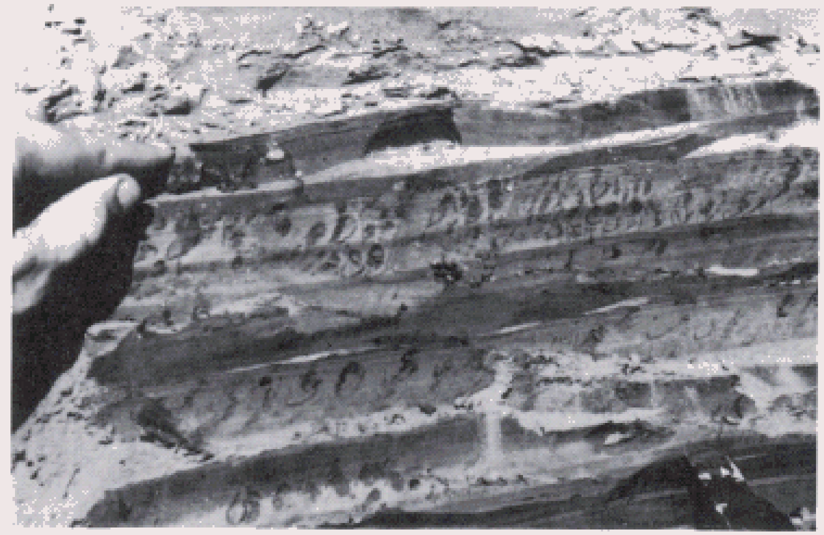


Figure 21. Varved clays at Hanover deposited on the bottom of the glacial lake which once occupied the Connecticut Valley. Each dark layer, a half inch or more thick, is clay deposited in quiet waters under winter ice. The sharp top of each dark layer (at the finger and knife) marks the beginning of spring floods. The thick light layers are coarse silt deposited in turbulent summer waters. Thus each pair of layers, one light and one dark, represents the deposit of one year. (Photo by R. P. Goldthwait.)

Detailed studies show that this is actually the case. However, any one year's deposit of the varve silts and clays changes from a sand layer a few inches thick near the ice to clay a small fraction of an inch thick at five to as much as fifty miles down the lake. In varve studies, therefore, we are not as much concerned with the actual thickness, which depends largely upon the local factors, but we must consider the relative thicknesses.

As the ice mass, cliffed where it met the warmer lake waters, wasted away northward year by year, the thin varve layers overlapped one another like shingles on a roof, the upper and later ones extending farther north into areas earlier occupied by the ice. A group of varves south of Hanover, for example, where most varves are a fraction of an inch in thickness, shows similar variations to a group exposed two miles away just west of Hanover, where the average thickness is about two to four inches (Figure 22). Despite the difference in actual thickness the variations may resemble each other so closely as to leave little doubt that the varves south and west of Hanover register the same series of years. By matching the variations in

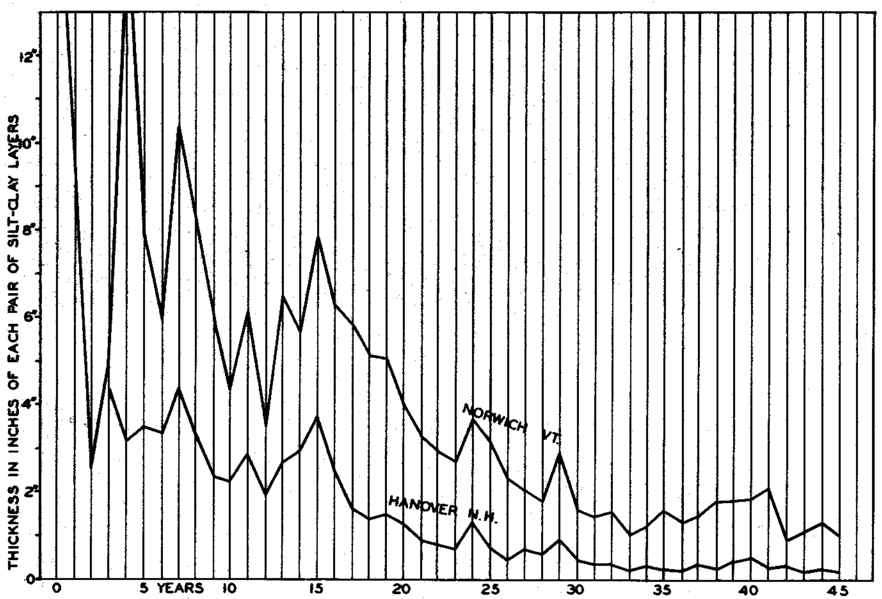


Figure 22. Matching of curves for the thickness of varves in the glacial lake which once filled the Connecticut Valley. The height of each line represents the thickness of each varve (light summer silt and dark winter clay, see Figure 21). The successive years from left to right vary in thickness enabling one to correlate years of thick or thin deposit from Mink Brook in Hanover to Lewiston in Norwich, Vermont. Zero year here is about 3,760 years after the ice began to uncover this lake basin at Hartford, Connecticut. (After Lougee.)

thickness, dozens of varve exposures were correlated for 200 miles up and down the Connecticut River valley by Ernst Antevs an expert from Sweden. He counted 4,100 different overlapping varves in the Connecticut Valley between Hartford, Connecticut and St. Johnsbury, Vermont.[1]

Wherever the bottom varves are found at two localities, and their relative dates can be compared, it is possible to work out the number of years that the ice border was melting back from the first to the second. For example, because the bottommost or first layer at Piermont is found to correspond to the 151st layer above the bottom at West Lebanon, it is clear that the recession from West Lebanon to Piermont took one hundred and fifty years, and the rate of retreat for the ice edge for the twenty-seven miles is over 900 feet per year. On this assumption Antevs computed rates of retreat of the ice cliff up the lake as great as 1,100 feet a year and averaging 238 feet per year. In one or two areas the ice lingering to the north had renewed activity, because it pushed back down the lake a few miles covering water-sorted varve silts with unsorted stony till laid directly by ice. The finest exhibit of readvance was unearthed at Fifteen Miles Falls power dam where varves above and below a till layer correlated with varves down the lake to show that ice readvanced back down the lake as much as 20 miles during 235 years.[2]

The ancient glacial lake in the Connecticut Valley stood at two different levels. For at least 3,559 varve years the earlier and higher stand, called Lake Hitchcock, lapped up against the ice mass as it disappeared from Connecticut until it reached Lyme, New Hampshire, the northern limit of its varve deposits. Then suddenly the surface of the lake dropped some 90 feet to a lower level called Lake Upham. In some of the most telling claybanks like that along Mink Brook in Hanover, the lower thin varves of Lake Hitchcock are overlain by a thick sandy *drainage varve* representing the turbulent, stirred-up waters as the lake lowered, and these are overlain in turn by the thin silt varves of Lake Upham on top.

Shorelines are poorly registered in these long narrow lakes. Where a stream entered Lakes Hitchcock and Upham, its coarse gravel load settled out as a small delta which blocked a tributary valley and is now high above the level of the Connecticut River. However, these scraps of deposit are difficult to distinguish from gravel kame terraces with delta

[1] Antevs, E. **The Recession of the Last Ice Sheet.** Res. Ser. no. 11, Amer. Geog. Soc. 120 p. 1922.

[2] Lougee, R. J. **Time Measurements of An Ice Readvance.** Proc. Nat. Acad. Sci., vol. 21, no. 1, p. 36-41. 1935.

structure washed against decaying ice. In few of them there is a typical lobate delta front. Undoubtedly some of these levels, plotted in painstaking detail by R. J. Lougee, are true delta levels. These fall on two levels corresponding to the two lakes.

The remarkable fact is that these once-level old shores are now sloping 4 to 9 feet per mile. The "delta" markers of Lake Upham lie near 800 feet at Woodsville, New Hampshire, and near 300 feet at the Massachusetts line. This shows that all the glacial lake valleys were tilted up by the progressive upwarping and uparching of the earth's surface where the ice had depressed it. Except by depressing northern New England, how could any of these inclined valleys have been low enough to hold continuous lakes instead of rivers?

Recently physicists have developed a method of telling how old lake or sea sediments are from the content of certain radioactive elements which change with time. One of the lowest varves near Hartford, Connecticut is thus about 18,000 years old and this means that the decaying ice began to uncover the Connecticut Valley in New Hampshire about 16,000 years ago, and that Lake Hitchcock dropped to Lake Upham 15,000 years ago. Very likely the last large mass of the Pleistocene ice sheet melted away in the State 14,000 years ago.*

* Some evidence now being explored in the St. Lawrence Valley to the north suggests that the ice readvanced near to New Hampshire only 11,000 years ago.

AFTERMATHS OF GLACIATION

Beginning of Modern Lakes

The tilting of the land described earlier spilled the three large glacial lakes out at least 10,000 years ago, and streams with a regular but gentle gradient took over. Down the steep and narrow valleys of the White Mountain region, the last floods of meltwater left boulder-paved channels which have become the river courses of today. One spectacular sharp gorge so excavated is The Flume in Franconia Notch.[1] The swift streams of this rugged area have cut continuous paths, leaving no ponds or lakes of late glacial origin except on or very near the heights of land in notches like Crawford (Saco Lake), Franconia (Echo and Profile Lakes,) and Kinsman (Beaver Pond) where dams of drift remain intact across flat valley floors. There are also those few small, high lakes wholly surrounded by bedrock and sculptured out of more vulnerable spots of solid rock by the glacier (Page 19).

Farther down, where the valley floors are wider and flatter among the foothills, one finds more lakes. Here are kettle hole ponds like Echo Lake in Conway where meltwater floods once spread a wide plain of sands around a lingering ice mass (Page 40). The broader the valleys the larger the kettle hole lakes, as for example Ossipee Lake. Overflow drainage has developed rivers through the flat sandy plains covered with pitch pine and scrub oak. Similar ponds in Conway and along Pine River or in Milton are flanked and largely enclosed by coarse gravelly kames, and kame terraces and partly or wholly bisected by eskers (Figure 23). For the 15,000 years since the ice disappeared, these larger lakes have been essentially as we see them today.

Most New Hampshire lakes and ponds occupy ground in which bedrock, glacial till, or outwash form the enclosing rim and floor. They occur at all altitudes, but are scarce and small at extreme high and extreme low elevations. There are 489 lakes and ponds in New Hampshire which exceed twenty acres in area and therefore are "great ponds" —the property of the State. Vermont, right next to New Hampshire, offers striking contrast with less than 200. Reasons for this contrast seem to be: (a) the more regular bedrock structure of Vermont where broad belts of schist run from north and south along deeply eroded folds; (b) the more southward flow of the ice sheet over Vermont, at

[1] McNair, A. H. The Geologic Story of Franconia Notch and The Flume. Concord, N. H. State Planning and Development Commission, 1949, 14 p.

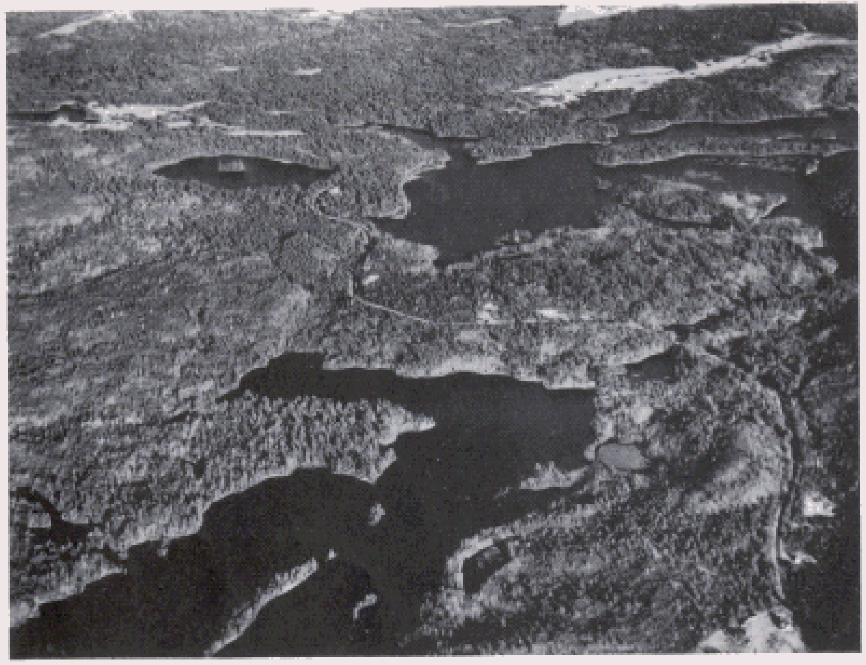


Figure 23. Irregular glacial deposits outlining the south end of Pine River Pond, Wakefield. The long narrow islands and points near the bottom are esker ridges of sandy gravel. Hidden by woods around the lakes are irregular hummocks called kames. (Air photo by H. B. Washburn, Jr.)

least in its final stage, nearly parallel to the topographical grain; (c) wider distribution of upland with deep pre-glacial valleys and without coastal or intermontane lowlands; and (d) the dearth of extensive pitted sandplains enclosing kettle hole lakes. The smooth north-south shoreline of Lake Champlain contrasts with Lake Winnipesaukee which has scrawny spreading arms and hundreds of islands as a result of the irregular pattern of weak bedrock areas, together with south-eastward glacier flow across this "grain" and deep preglacial weathering.

Drifting Sands

In late glacial time westerly winds of gale force, intensified by the cold ice sheet as in Greenland today, swept clouds of sand across the bare surfaces of broad outwash plains east of Ossipee or Concord. Heavy forest cover did not come immediately at all places before sand dunes formed. As lakes drained out of the Merrimack and Connecticut Valleys, exposing wide flat floors of loose, fine sand unprotected by

Figure 24. A wind cut stone, "ventifact" from Exeter. Sands, drifting across plains of glacial outwash before vegetation was so dense, smoothed the faces of such pebbles. This pebble is 1¾ inches long. (Photo by D. H. Chapman.)

vegetation, dunes began to migrate up the hillsides especially toward the east, as east of Pine River in Effingham. Sand grains repeatedly swept over the dune crest and settled down the lee slope, causing each dune to migrate a few feet a year.

These dunes cannot readily be distinguished from low sandy kames by their moundlike form; but where the interior is revealed as in roadcuts, the uniform coarseness of the sand and the utter absence of pebbles and stones will identify them as wind blown. Thus came to be the low mounds on the Dark Plains of East Concord and others three miles west of Canaan, or a few miles north of Rochester and in Hinsdale.

On the floor of Lakes Hitchcock and Upham in the Connecticut River Valley where the wind found silt and fine sand rather than coarser grains, dust storms spread an extensive smooth layer of silt called *loess*. This particular type of deposit a foot or two thick fits the specifications for commercial molding sand, but it has not been traced out of the Connecticut River Valley.

Here and there, as in South Grafton and Danbury high up among the hills where sandy kames formed in pockets marginal to the ice, sand dunes occur, accompanied by stones of "Brazil nut" form etched, faceted, and polished by the blast of drifting sand. Another of these rare stones dicovered in Exeter is seen in Figure 24.

Frost Splitting on Mountains

During the uncovering of summits of the White Mountains by the melting ice sheet, intense frost action split ledges into angular blocks, moved them about, and redistributed the till and boulders. Millions of these frost-cracked blocks make the cone of Mt. Washington look

Figure 25. Mt. Washington, the top of New Hampshire, looks like a pile of rocks but it is really solid bedrock covered with a veneer of blocks split off by intense frost action at the close of the Ice Age. Beyond the summit hotel is Tuckerman Ravine. (Air photo by H. B. Washburn, Jr.)

like a great rockpile even though solid ledge lies only a few feet down (Figure 25). For a considerable time while only the very surface of the mountain was thawing and being loosened from the frozen ground under it, all the high-level blocks and juicy dirt masses were slowly moving downhill.

The most striking result of this prehistoric frost action is the gathering of rough stones from the soil into belts which form patterns like a net over the flatter surfaces, or like stripes and festoons on the slopes. This involved two actions: (1) the segregation of larger stones and blocks out of the finer soil masses, and (2) the squeezing of these stones together into stone belts a few inches wide or block belts a few feet wide. Apparently the stones and blocks were forced outward from dirt centers. Upon freezing, the whole soil mass expands outward from the clay-rich centers which hold more water, and as it thaws, some of the fines seem to fill spaces occupied formerly by rocks thus crowding them outward. As adjacent soggy soil centers expand repeatedly, stones and blocks from opposite directions are squeezed together to form a boulder-filled trough. The slabby pieces are jammed together so tightly that many stand up on end like tombstones.

The pattern formed on the surface by these stone and boulder belts depended largely upon steepness of slope. On flat land like the "lawns" of the Presidential Range many-sided rings or *polygons* of boulders joined to form a net-like pattern. On gentle slopes of five degrees or so these were dragged into *stripes* stretched directly down slope by the creep of thawing soil (Figure 26). This soil is very juicy in the late spring when accumulated winter ice melts out. Where stunted trees and sedges gained a foothold the creeping ripped the turf mat apart and squeezed segments of turf on edge to form risers three feet high into a series of broad stairs. On slopes steeper than ten degrees, relatively rapid flow of soil forced the fine soil centers to pile up against steep teardrop shaped walls of large blocks squeezed ahead of the creeping mass. Scores of these formed on the cones of Mt. Washington and Mt. Jefferson. Of course, the clay-rich soil centers are now covered with turf growth and a few lingering stones. These large rock patterns appear to be the relic of the cooler climate right after glaciation, for the boulders have little if any motion today. Even the boulders in the foreground of stereoscope pictures taken in the 1870's show no shifting except where man has moved them.

Figure 26. Miniature stone stripes on the Old Crawford Path across Bigelows Lawn just southwest of the cone of Mt. Washington. Like most evidence of present-day sorting in the soil, which requires intense frost action, this is at high altitude (5,400 feet) on exposed mountain slopes. (Photo by R. P. Goldthwait.)

Miniature stone patterns similar in form but smaller in size, are produced even today on open soil patches above four thousand feet (Figure 26). On a few open lower peaks like Mt. Cardigan or Mt. Kearsarge nets and stripes of pebbles in bands a few inches apart form in a few years.[1]

Landslide Scars

In the mountainous regions cliffs and crags were so cracked and loosened during the melting away of the ice sheet that great blocks fell into confused masses at localities like Lost River and Polar Caves. Since the ice wasted away, cone-shaped heaps of *talus* have continued to accumulate more slowly in ravines below steep cirque walls as in Great Gulf or Huntington Ravine. More continuous thick aprons of talus a mile or more long have been banked up under the high cliffs in Carter and Crawford Notches. The surface of each cone or apron inclines downward at thirty to thirty-five degrees, because a rockpile can stand no steeper. Even this is steep to climb and offers insecure footing. Under the larger blocks in the lower parts of some talus the irregular openings are connected as limited caves. Ice, frozen in winter from groundwater, may last far into the summer in these protected refrigerators. Each summer a few curious parties seek out the hard-to-find ice caves like those on the north side of Green Mountain, or in Carter Notch, and under the "knees" of Mt. Jefferson.

A few of the largest talus piles actually crept or "flowed" as a short *block glacier* down valley under the influence of former cooler climates or on dwindling masses of glacier ice. One great thumb-shaped lobe, several hundred feet wide and composed of jumbled blocks, moved down across the gentle floor of King Ravine for over a mile. The Over-and-Under Trail winds in and out under the ten to thirty foot long blocks of this ancient talus.

Most of the steeper slopes of the White Mountains bear the scars of catastrophic *landslides*. These occur today at times of heavy rainfall (2 to 8 inches) when the thin soil supporting a forest cover is loaded by heavy rains, so that it need only tear loose at one spot on a steep, smooth bedrock slope to gather momentum and sweep a clean path down the mountain (Figure 27). Once started the loose earth sweeps all soil, boulders, and trees into the valley below with the roar of a freight train. A jumbled heap of logs, mud, and blocks comes to

[1] Denny, C. S. Stone-rings on New Hampshire Mountains. Amer. Jour. Sci., vol. 238, no. 6, p. 432-438. 1940.

Figure 27. Landslide scars in Franconia Notch. Heavy rains in 1948 made the soils soggy and lubricated the glaciated bedrock beneth. On steep slopes this sheet of heavy soil tore loose and wiped out trees and rubble all the way down the mountainside. The debris slid across the flat valley floor blocking the highway completely.

rest, and it takes many years for forest to grow in again on the bare ledges.

The material spread by the Willey Slide of 1827, historic because it wiped out a family of 9, has been largely removed for grading purposes but part of it can still be seen in section beside the highway northwest of the present Willey House. The Cherry Mountain Slide of 1885 reaches almost to Cherry Mountain Station and the steep track it followed down the mountainside still shows as lower forest growth of a different shade of green. Great slides from Mt. Lafayette in Franconia Notch closed the highway for weeks in 1948. Smaller slides, half torrent and half landslip in origin, have left bare scars after violent rains in November, 1927, March, 1936, and September, 1938 on Mounts Adams, Osceola, Moosilauke, Tripyramid, and many others.

Arctic Life on Open Summits

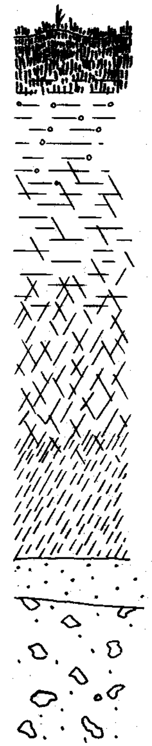
The bleak summits of the Presidential Range above treeline present a strange world of plants and insects which has long been recognized as an Arctic colony whose natural habitat extends from Labrador northward. There is no other colony in New England quite like it except one on Mt. Katahdin in Maine. Many of the flowering plants, sedges, and grasses are strictly limited to these summits; others like "Greenland daisy" (Arenaria) appear on certain lower mountains and in odd spots elsewhere in New England as on the lower Kennebec River. Both the Alpine and Subalpine Zones have been recognized by botanists on Mt. Washington.[1] Other subalpine colonies occur on the Franconia Range and Mt. Moosilauke. Long severe winters, fierce winds, isolated patches of soggy frost-ridden soil conspire to prevent the growth of the native New Hampshire flora, but these same severe conditions offer refuge for some of those Canadian Arctic species which could grow down in New England during the Pleistocene Ice Age. Since the ice sheet surely covered these highest places (Page 17), we cannot accept the view of certain botanists[2] that the Arctic plants lived here on nunataks throughout the glacial period. Indeed, other examples of arctic plant colonies at lower elevations, as on the shores of Lake Superior in the very heart of the most recently glaciated region, deny that botanical theory. It would seem likely that after they had begun to grow southward and southeastward beyond the limits of glaciation off Long Island and George's Banks, this assemblage of plants, and the insects that accompany them, found their way back across the hilltops and ridges of the New England upland while downwastage of ice was uncovering them. The spreading of plants northward might come about more readily if, as we now think, the ice thinned down so as to uncover ridges over a wide area and provide innumerable paths for migration. As increasing warmth overspread the region, they were limited to higher and higher White Mountains until at last only the highest summits remained wintry enough to support them. Study of pollen records may verify this simple theory, for under the forest litter of some bogs in Maine, there are only the pollen of arctic plants like those of northern "tundra" today.

Changing Climates

The change from the glacial climate to the warmer one today seems to have come slowly and with interruptions. The best records of these variations of temperature and humidity are to be found in deposits of peat which have continued to accumulate in poorly drained basins from successive generations of plants and trees. Botanists have developed skill in separating these amazingly durable little cells

[1] Antevs, E. Alpine Zone of Mt. Washington Range. 118 p. Auburn, Me. 1932.
[2] Fernald, M. L. Persistence of Plants in Unglaciated Areas. Amer. Acad. Arts and Sci., Mem., vol. 15, pp. 237-342. 1925.

FIGURE 28.- LAYERS IN NEW ENGLAND PEAT BOGS (AFTER DEEVEY)



Portion of bog	Abundant pollen type	Climate compared to today	Probable time
	Hemlock Spruce returning	More moist and/or cooler	500 to 2000 years ago
	Oak Hickory	Drier and warmer	2000 to 3000 years ago
	Hemlock Oak	as moist and warmer	3000 to 6000 years ago
	Pine	Drier and warmer	6000 to 9000 years ago
	Spruce Fir	as moist and cooler	9000 to 14000? years ago
	(Dryas "tundra" in Maine)	Colder	11000 to 16000? years ago
	Glacial till	Much colder wetter?	14000 to 16000 years and more

of pollen from the more rotten peat mass, identifying each species of plant represented, counting percentages, and discovering how the flora changed as the bog built up inch by inch.

In New England a well planned investigation of past forests is beginning to divide postglacial time into definite climatic substages (Figure 28), just as it has done in central United States and Europe.[1] Of course no *one* forest type characterizes the Granite State today—hardwoods deck the hills, pines cover the well-drained gravels, and spruce-fir woods cover higher mountains or "north country." As the ice sheet melted in adjacent Maine, there was a brief Arctic time when treeless "dryas" grew like the present tundra. To the south,

[1] Deevey, E. S. Jr. Studies on Connecticut Lake Sediments. Amer. Jour. Sci., vol. 237, no. 10, p. 691-724, 1939, and Additional Pollen Analyses. Amer. Jour. Sci., vol. 241, no. 12, p. 717-752. 1943.

in Connecticut, spruce and fir covered the glacial drift first. With more warming came drier pine and birch forests of *Boreal time*. Finally some 5,000 years ago came the oaks and hemlocks of *Atlantic time*, which was warmer and/or wetter than today. All of these forests may be seen in reverse today as one drives from moist lowland to drier outwash plains in central New Hampshire and thence to a high fir-clad notch in the mountains. And the treeless Arctic flora still exists on top of Mount Washington!

The stage when the climate of New England was definitely warmer than now is indicated by oysters on the coast of New Hampshire and Maine and by fossil specimens of southern cedar trees in seacoast swamps. Oysters (*Ostrea virginica*) still grow in a native oyster bed in Oyster River at Durham although no other native oyster colony exists north of Cape Cod. In colonial and pre-historic time oysters grew in other places of refuge; in Back Bay, Boston, in Portland Harbor, at Sheepscott Fall, and at Damariscotta, Maine where they were eaten in quantities by early settlers and Indians. The oysters had worked up tne coast past Nova Scotia into the Gulf of St. Lawrence then the waters of the outer coast became too cold.

Cedar stumps (*Chamy cyparis*) comparable in size to trees now confined to the Carolina coast and Delaware have been dredged up from drowned forest beds behind barrier beaches as far north as Centerville, Cape Cod. Rings of growth show that some of them lived to be 450 years old. Since they died the sea has risen and covered them with marine muds, salt marsh, and beach deposits.

Since five thousand years is only a small fraction of the length of time which separated successive glacial stages, we can claim that we too are living in the Ice Age. Having gotten warmer since the last major glacial invasion than today, the climate may become both warmer and cooler several times before there is a permanent warming up or another cooling off sufficient to bring glaciers down upon us. During most of the earth's history, climate in the polar regions has not been extreme, so the existing ice sheets of Greenland and Antarctica warrant the view that this is still a part of the Ice Age which we live in, although it is a milder part of that ice age.[1]

[1] **Flint, R. F. Glacial Geology and the Pleistocene Epoch. New York, p. 206-207. 1947.**

LANDSCAPE IN THE MAKING

Seashore Changes

The variety of features along New Hampshire's short shoreline have come into being while sea level and then land were rising after glaciation. Great Bay occupies a drowned valley where four branches of the Piscataqua River joined centuries ago to discharge along a single path through the valley which is now Portsmouth Harbor. As the sea rose and fell on the coast, it encountered low rocky hills at Odiorne's Point and Straw's Point, and beat against them without moving much more than the loose cover of glacial till and boulders. The final establishment of present sea level left a lone drumlin as an island at Great Boar's Head. The east end and sides were eroded back into a high seacliff which still suffers damage from storms wherever the breakwaters are weak. The eroded remains of the drumlin have long since become tied to the mainland by a *tombolo* of sands gathered by waves and currents in the lee of the island.

Sand and gravel were swept from the glacial deposits along the seashore, and were cast up by storm waves into low even-crested beach ridges above the level of highest tides. Coarse material is cast up by high waves to the higher parts of the beach, but only fine materials can be dragged out seaward by backwash. These sands are dragged along the shallow shore by obliquely striking waves to add *bars* across bays or *spits* off open points as at the mouth of Hampton Harbor. Ultimately they close off inner bays as lagoons like Great Pond and Eel Pond. At Foss's Beach the wind has gathered an excess of sand into *sand dunes* which rise fifteen to twenty-five feet above the reach of the waves.

Into the broad, sheltered lagoons behind these beaches, mud and silt have come with each incoming tide. Part of the silt has been caught by salt-tolerant grasses to build extensive mudflats and salt marshes. The marsh surfaces have continued to build up as fast as sea level has risen.

The almost perfectly level surface of the salt marsh stands at mean high water mark. The supply of mud is ample to build up the deposits to that level and to maintain it there even though the marsh sinks slowly due to compaction and vegetable decay. The long, slow rise of sea level during the construction of the marshes is proved by the presence, from top to bottom, of roots and tissues of the very same grasses which today cover the surface. They have such definite salt

Figure 29. Drowned forest at Odiorne's Point in Rye. When the sea was much lower the stumps in the foreground and right were growing pines, hemlocks, and birches because, they are rooted in the till beneath. As the sea advanced, salt water destroyed them and beach sand may have covered them. Now, decades and centuries later, the covering sands have been washed away but high tide still covers them. (Photo by J. W. Goldthwait.)

requirements that they are unable to live more than a foot and a half above or below mean high tide.

Under some of the marsh deposits lie the remains of a layer of forest litter like that on the upland areas today, where the roots of stumps still grip the underlying soil (Figure 29). At Jeness Beach and Odiorne's Point small patches of drowned forest remain near low tide mark, battered and ground by waves and shore ice. The wood is so well preserved that samples cut from many stumps have been identified and the annual rings of growth have been measured in an attempt to discover the relative dates at which the trees died as the sea crept up among them.[1] Evidently, as the sea advanced on the land, killing the primeval forest and starting to spread tidal mud, these highwater grasses established themselves and have continued to flourish and catch mud as the sea level rose higher and higher.

It has been argued from the growth of marshes that sea level is still rising at a rate of nine inches a century. If so, we would expect: (1) that forests would be killed along highwater mark rather generally;

[1] Lyon, C. J. and Goldthwait, J. W. **An Attempt to Cross-date Trees in Drowned Forests.** Geog. Rev., vol. 24, no. 4, p. 605-614. 1934.

(2) that ledges along the coast now would stand measurably lower in relation to tide levels than they did a century or more ago; and, (3) that the boundary line between the salt marshes and the sloping uplands would stand farther inland today than it stood in the 1850's when it was mapped in good detail by the U. S. Coast and Geodetic Survey. But none of these conditions is true.[1]

Winding creeks of extraordinary symmetry traverse the marshes, letting the sea flow in and out over every part. Their graceful curves are far more symmetrical than the irregular crooks and bends of freshwater river meanders—chiefly because the creeks occupy land that is almost level and uniformly soft in composition, and because currents run alternately in and out in two complete cycles each day with far greater regularity of discharge than is anywhere possible for rivers fed by rainfall. These *tidal estuaries* broaden rapidly seaward, especially near their mouths where they flare like trumpets (Figure 30). By these changes of form the estuaries express a nice adjustment between

[1] Goldthwait, J. W. **Vertical Stability of the Coast.** Amer. Jour. Sci., vol. 35, p. 81-93. 1938.

Figure 30. Salt marshes in back of Hampton Harbor. Symmetrical meander curves are made by tides which flush in and out twice daily. Hampton Beach is in the distance and Great Boar's Head to the left. (Air photo by H. B. Washburn, Jr.)

channel cross-section and volume of tide reaching each point in the drainage system. Indeed, the discovery that the tiniest of the *meanders* as well as the largest of them have remained unaltered by scour or fill since the 1850's and the 1860's, suggests that over the centuries they have attained a degree of stability that is rarely matched in the record of geologic changes on the surface of the earth.

Lake Shores Altered by Ice

In the 15,000 years or so since the departing ice sheet left ponds and lakes in ill-drained places in New Hampshire, only minor changes seem to have taken place in their outlines or depths. Some pools, usually small and shallow, have become bordered by a quaking mat of decaying sphagnum moss or completely filled by soft peat deposits, others have been raised or lowered a little for man's use.

On the larger lakes, such as Winnipesaukee, Newfound, Sunapee, and Squam waves become large enough to swamp a small boat during days of heavy winds, but these waves are so infrequent and short lived that their effect has been small indeed in cutting back exposed points to form bluffs or in washing sand or stones up into pocket beaches. There are no raw banks of glacial drift, even on Lake Winnipesaukee, to compare with Great Boar's Head on the seacoast. The best are low wave-cut points like Clay Point in Alton. Generally where stony till rims a lake and the slopes are gentle, waves have washed away the sand and silt leaving stones and larger rocks for winter ice to catch hold of and move ashore. If one can draw conclusions from shore profiles, the cutting back of shore bluffs by waves, in the most extreme cases is but twenty or thirty feet.

The meagre development of shoreline features around the lakes and ponds may be due to the artificial high level at which they stand, for scarcely a New Hampshire pond stands today at its natural level. They have been raised a few feet in earlier centuries by dams for local power development or for storage in connection with use of power downstream. Some of the largest, like Winnipesaukee, Wentworth, and Great East Pond were both dammed and ditched at their outlets to gain both the higher storage and a greater draw-down below the natural level—a matter often calling for settlement in the courts or special act of the legislature.

Although the lake shores have been changed little by waves, as compared to the ocean shore, the effect of lake ice is readily evident. During the colder months of the year when the lakes are frozen, with little snow cover, the ice alternately expands and contracts as air

temperatures rise and fall. The loud cracking of the ice on extremely cold winter nights is caused by shrinking of the ice as it is chilled. Water seeps into many of these cracks and freezes. Later, when the temperature rises, the ice expands so it has to buckle into ice ridges or push onto the shore. Common temperature changes of twenty degrees may cause an expansion or contraction of three feet in a lake one mile in diameter. Since many New Hampshire lakes have a diameter considerably greater than a mile, it is not surprising that the ice may shove many feet onto the shore, jamming against boathouses and wharves, plowing up the beaches and rocky shores, or upturning tree roots and scraping tree trunks at the edge of the lake.

Ice thrust also comes at the time of "spring breakup." In late April melting snow and spring rains raise the level of the lake. The continuous ice cover breaks into floating cakes blown by the wind. Ice near the shore is frozen to protruding rocks and as the lake level rises this ice is blown by wind onto the shore carrying some boulders and pushing others. The onshore progress of boulders season after season is found in paths left by isolated larger rocks dragged by the ice through the pavement of smaller rocks or sand. Boulders which have been located in the fall and relocated in the spring move ordinarily a few inches in any one year. The paths are sometimes straight, but more often zigzag. One of the most impressive examples of these boulder trails is that left by a rectangular boulder weighing approximately 75 tons on the northeast side of Stamp Act Island in Lake Wentworth. This huge boulder over a period of years has been shoved 155 feet in three slightly different directions leaving a continuous trail behind it.

Within a century or two most large and small rocks from shallow water are slowly concentrated at the steeper waterline as a pavement. On the gentler sloping shores the ice has shoved the rocks into ridges 3 to 10 feet high just above the edge of the lake. These are known as *boulder ramparts,* and they are enduring marks of lake level. Examples of these ramparts may be found in most any New Hampshire lake which is over a half mile in diameter, provided that the lake level has not recently been changed (Figure 31). On Little Sunapee Lake patches of ramparts may be found on all sides of the lake which is nearly bisected by an esker. It is known that the ice each year not only pushes rocks onto a growing spit at the end of the esker but also along the sides so that a spit has now grown nearly completely across the lake. Where ice regularly shoves diagonally past a point or island, a curved spit or bar of boulders too big for waves to move is built.

Figure 31. Rampart of boulders and turf pushed up by expansion of the ice in Lake Wentworth, beside Route 109 in Wolfeboro. (Photo by L. Goldthwait.)

Thus the *boulder spits* opposite Clows Beach in Lake Wentworth grew or the *boulder bars* in Lake Winnipesaukee which are being made each spring, tie Black Island to Moultonborough Neck, and connect many tiny islands at the end of that neck.

Active Soils

A familiar feature on New Hampshire farms where fields slope steeply is the display of little steplike benches or *cow paths*. In some European countries they are popularly supposed to owe their origin to the trodding of the cattle grazing along them. But anyone familiar with the haphazard ways of small herds of grazing animals commonly seen on New Hampshire hillsides will suspect the popular theory and look for other causes. Some benches occur on banks and bluffs in the Connecticut and Merrimack valleys where horizontal layers of lake floor clays and silts tend to concentrate groundwater and frost action at certain definite levels. Yet distinct cow paths occur also on the flanks of some gravelly eskers, and often on slopes of impervious stony

till utterly without bedding. Some cow paths are claimed by landowners to be furrows produced by contour plowing, thirty or forty years ago. Perhaps some examples are indeed sheep tracks for during the periods of 1830 to 1850 and again 1870 to 1880 farms, particularly in the Connecticut Valley, were overrun by tens of thousands of sheep. But many of these steps, especially those where herds have never ranged, are thought to develop under the heaving influence of frost. Whether they be the result of plowing, grazing, or frost remains a question for someone to investigate.

Wet pastures on gentle to moderate slopes are often dotted with little hummocks of vegetation or *turf hassocks*, the cause of which is imperfectly known. Upward push of rocks by frost may bulge up the soil and turf cover, but only a few have boulder cores. The heaping of soil by uprooted trees of a former forest cover contributed some irregularities. Vigorous growth of certain thickly rooted plants where the ground has an excess of moisture seems to account for certain small mounds which contain only plant material. Last but not least, the repeated upward and outward freezing from centers of wet clay-rich ground surely has a place in their development. In some subarctic countries such frost-swelled mounds are common. Perhaps the hassocks of New Hampshire stem from most or all of these causes.

Regularly each spring the New Hampshire farmer clears his field of new boulders. Some will tell you "they grewed there." Actually these are boulders of rocks which formed millions of years ago and were pushed by frost to the surface of the loose glacial drift. With each penetrating cold snap ground frost grips the tops of boulders at deeper and deeper levels to a depth of two to six feet. Because the freezing soil expands, as does all freezing water, it lifts each boulder and opens a thin hollow under the boulder. As thaws free the dirt below the boulder, and excess moisture makes soggy ground, wet mud and clay ooze into this hollow. Thus, when the ground is completely thawed some boulders have moved a little higher in the dirt mass and cannot fall back.

Shifting Rivers

Like the rest of New England, New Hampshire floods gather and discharge so irregularly as to seem almost haphazard. This irregular concentration and discharge of flood water is due largely to the irregular terrain and the spotty distribution or rate of rainfall. Measurements of precipitation at mountain stations in New Hampshire indicate that lateral deflection of air currents and local updrafts among the mountains cause very uneven precipitation. Irregularity is caused also by the uneven snow-cover on the hills and mountains as well as the distribution of forest and open country. Generally mountain tops get the most rainfall, up to 60 or more inches per year as compared to 40 inches in lower areas. Runoff is increased if the ground is frozen tight forcing all the water to go directly into rivers without soaking in. This happened in the November, 1927 flood. In the flood of October, 1869, the ground was already saturated by previous storm and could not absorb more water. Obviously the sudden thawing of snows, which store up the winter's precipitation, concentrate runoff so that "spring freshets" are the most common floods.

The runoff moves at different rates and will become concentrated at many points. Once the rainwater has reached definite channels the flow is irregular, for at many places streams have dug down to ledges of bedrock and developed rapids where the water tosses and foams. They afforded water power for innumerable sawmills, gristmills, and factories from the earliest settlements down to the 1860's or 1870's, but by now most of the mills and the waterwheels have fallen in ruins and been erased by severe floods. Only a few stone foundations and sluiceways survive. Upstream from these ledges and dams a stream course may wind in loops or meanders across a plain of flood deposits. The broad intervales one or two miles wide afford enormous storage at time of flood when the water may spread over them as much as five or ten feet deep. The volume of river water flowing down the valley may be swelled to one hundred or more times the normal discharge. These characteristics alone, on a river like the Merrimack, would cause floods to gather and move down-valley at uneven speeds (Figure 32).

Floods are really much more complex than that, for a river consists of separate tributaries which join from both sides, and each one of them has the bottleneck and basin character. These stream patterns, best seen on a map which shows only the bare outlines of the streams, are all formed with branches some long and some short. Some tributaries like the Pemigewasset River or the Wild Ammonoosuc River in New Hampshire have beautifully convergent drainage patterns so that they concentrate their flood promptly with peak discharge reaching the main river within six hours after the climax of the rainstorm. Most other New Hampshire tributaries, notably the Mascoma, Sugar, and Squam Rivers, are relatively well controlled because the terrain they drain is lower, and marshes, ponds, and lakes, have large storage capacity to delay the discharge. On a long drawn-out system like the Connecticut River the tributary floods coming into

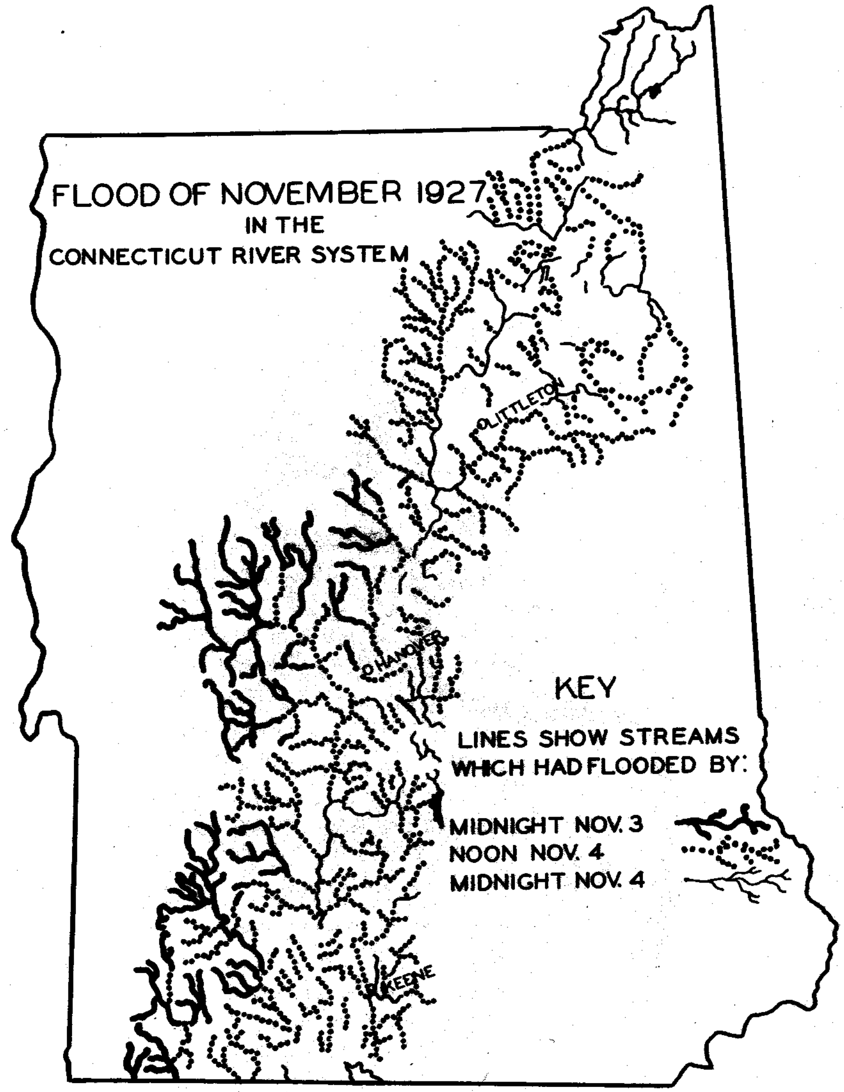


Figure 32. Progress of the crests of the 1927 flood down the Connecticut Valley for each 12-hour period. Since the storm travelled from southwest to northeast, the streams in southern Vermont flooded first, then those in northern New Hampshire. This poured highest floodwaters into main Connecticut River at different times in different parts of its long course.

the main stem at points miles apart, tend to produce a long slow flood rather than a short fast flowing one.[1]

[1] Goldthwait, J. W. The Gathering of Floods. Geog. Rev., vol. 18, p. 428-445. 1928.

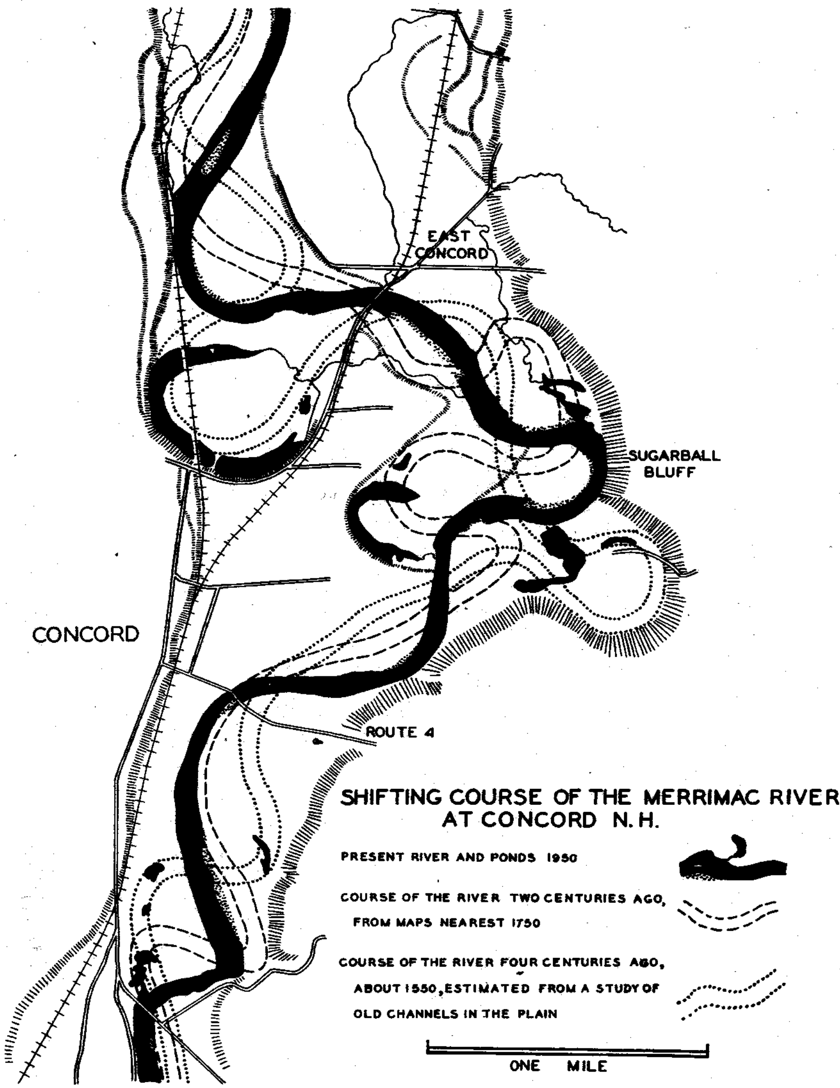


Figure 33. Changes in the course of the Merrimack River on the plains near Concord. Each position is represented by long shallow ponds, swamps, or a depression scar in the modern floodplain. By these relics and early Proprietors' maps courses 200 and 400 years ago are suggested in dashes and dots.

Where the main valleys of the Merrimack and the Connecticut were filled with outwash and lakebeds scores or hundreds of feet in thickness, the rivers have performed grand feats of sculpture. Up-

stream from each rock threshold, they swing in fairly symmetrical meanders trimming back the soft bluffs until they hit protecting ledges, and creating those wide fertile flood plains known to the Indians as the upper and lower "Coos" on the Connecticut, and to early settlers as "intervales." Steplike *terraces* appear on either or both sides of the valley, for often each tread is at the level of some protruding bedrock barrier where the river was held up until it shifted to the right or left.

The ceaseless shifting of the meander curves on these intervales is well recorded in the short 300 year history of white man. The earliest proprietors' maps of Concord show sharp S-shaped meanders of the Merrimack River around Hales Point near the Sugarball. In 1827 and 1829 the river severed the narrow necks of these curves temporarily shortening the river course and radically changing the maps of the 1850's. Now new meanders are again spreading laterally outward (Figure 33); the Fan east of Concord cuts two to five feet a year into Sugar Ball Bluffs. A few lakes like "The Horseshoe" at Concord are prehistoric channels abandoned when meanders were cut off and the course was shortened. The same history of gradually shifting curves and short cuts can be traced on the Pemigewasset River near Plymouth, on the Saco River north of Conway, and on the Connecticut River near Lancaster, Haverhill, and Westmoreland, and on innumerable smaller streams.

The intervales or *floodplains* are broad and flat due to the slow accumulation of sand and silt during the waning stages of each flood. Rapidly moving waters undercut the outside bank on each curve supplying new silts, sands and gravels. Floodwaters do not always limit their cutting to the channel banks; when the flood is high enough to flow deeply over the floodplain, it digs sharp gullies into the neck of some meanders and scours out perfectly elliptical *swirl pits* twenty to fifty feet long under a sharp eddy. The sand and gravel thus gathered drops to the bottom where it reaches the slightly slower moving water on the inside of some nearby meander bend. The silt makes the floodwaters muddy, and it settles far from the channel over backwater swamps. Thus it adds silt layers on top of the sands and gravels, and fertile intervales are built where the river once flowed.

Water Under the Ground

The floods of rivers during each heavy rain make it obvious that some rainwater flows off directly into streams. In New Hampshire this seems to be about one third of all rain or about one foot per year. However, we seldom contemplate how these rivers keep going during drouths between rainfall. Of the two thirds of each rain which soaks into the ground, one half is stored as groundwater and the rest evaporates or is used by plants. Ultimately most of the groundwater slowly seeps into a river or lake or issues in springs to keep rivers flowing all the time.

There are signs that the ground was wetter and more soggy just after glaciation than it is now. High above the present course of Mink Brook in Hanover there are old meander channels with a width and size of curve greater than that today. The meanders have been cut off so that new deeper and more narrow channels serve the brook. Among many examples the most notable is the abandoned channel of the Mascoma River east of Lebanon which is complete with a waterfall. It is described by Jeremy Belknap as far back as 1792. All over the State the melting ice sheet left the ground saturated with water. As the Connecticut and Merrimack, and their branches cut valleys down through the loose deposits, so much water seems to have oozed into the channels that for a while small tributaries had volumes several times the amount they now get from rainfall.

With ample time for groundwater to accommodate itself to local trenching by streams and to climatic changes, the *watertable*, or top of saturated ground, now has come to have a rather stable position in the ground. It is commonly 5 to 25 feet below the surface. But its seasonal rise and fall as it is swelled by melting snows in spring and starved by summer drouth, is generally marked enough to affect surface wells and some wells drilled deep into rock. Water supply has become an increasingly serious problem with the use of thousands of New Hampshire farms and cottages which demand more and better water. Glacial till, in which most hillside wells were dug in the old days, is too compact and clay-rich to permit easy movement of water into a well. Thus, the timeworn dug well three to five feet wide and some twenty feet deep receives its water slowly from a wide area and it fluctuates up and down with the season.

In recent years more and more New Hampshire landowners have had wells drilled down into solid rock. These wells pass through water-filled joint cracks which generally are inclined at steep angles

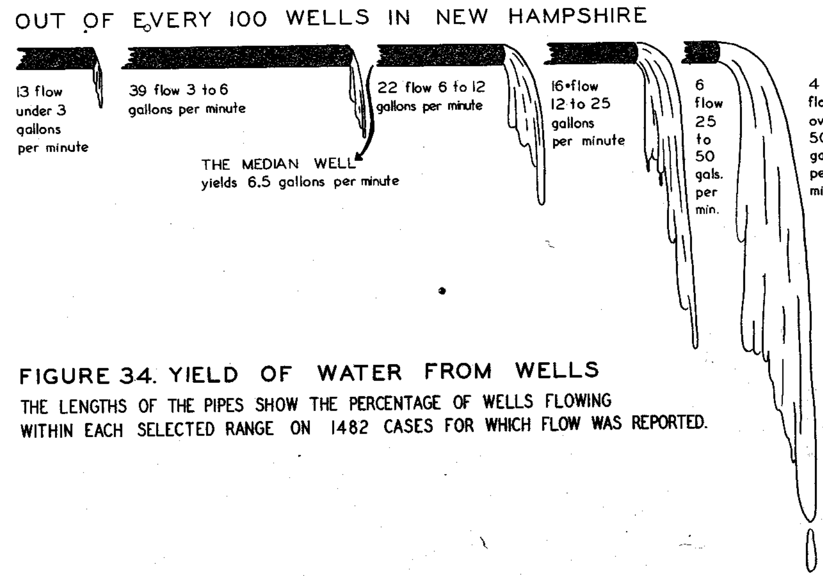


FIGURE 34. YIELD OF WATER FROM WELLS
THE LENGTHS OF THE PIPES SHOW THE PERCENTAGE OF WELLS FLOWING WITHIN EACH SELECTED RANGE ON 1482 CASES FOR WHICH FLOW WAS REPORTED.

through the rock and receive the water from rain soaking through the loose soil above. If we assume an annual addition to the groundwater of one foot of rain, it would take 12 acres to keep one crack supplied at 8 gallons per minute. In a study of 1,600 such wells the ones under porous sands and gravels in valleys yielded water more rapidly, averaging some 8 gallons per minute.[1] Others fed by water moving more slowly through a tight till cover supply only 6 gallons a minute. Actually the individual wells vary greatly, for one out of 22 wells never obtains any flow of water, and only one out of 5 wells will strike water which can be pumped at the rate of 10 gallons per minute (Figure 34). The hazards of penetrating jagged cracks which are irregularly connected to the water-feeding soils above, make drilling unpredictable and only a fairly good gamble.

Drilling to a great depth does not better one's chances of more water, nor assure one of greater purity. Records show that some deep wells of over 500 feet get no water while others yield enormous quantities (over 50 gallons per minute), but they average only 7 gallons per minute as do shallow wells. About the same proportion of deep drilled wells send in contaminated samples for Health Department testing as do shallow drilled wells or dug wells.[2] So perhaps 100 to 200 feet is the optimum depth to drill.

[1] Goldthwait, R. P. **Artesian Wells in New Hampshire.** Part 11, Min. Resource Surv. Concord, N. H. State Planning & Development Commission, 1949. 24 p.
[2] Healey, W. A.; Larviere, F. J., and Gilbert, W. C. **Characteristics of Shallow and Deep Wells.** N. H. Health News, vol. 26, nos. 9-10, p. 112-122. 1948.

IN RETROSPECT

Ever since the first gathering of muds and sands in Paleozoic seas, and up to the most recent slow shifting of the banks of the Merrimack River, the story of New Hampshire has been one of regular slow change which is still going on before our eyes. There was no catastrophic deluge greater than the floods of 1869, 1927, or 1936. By painstaking study the whole record of the rock surface and dirt suggests a slowly shifting scene from lowland plains and hills (the New England peneplain), to areas of deeply eroded mountains (the buried valleys), and a Greenland-like ice sheet scraping the surface and dumping the dirt in new places (the Wisconsin glaciation). This is the doctrine of uniformitarianism, pronounced nearly two centuries ago, namely: That the same slow erosion and deposition which we see in various lands today can account for the valleys and plains of yesterday. Except for the rare great flood or storm these changes are so slow that it is hard, in one short lifetime, to conceive how the whole landscape can change during a long million years. Yet the old weathered drift of southern New England and the glacial cirques in the White Mountains show that there were early stages when New Hampshire looked more like western Greenland. Climate and vegetation changed from the severe arctic climate after glaciation, which split ledges on the higher mountains, to a period about 5,000 years ago when life in these parts was warmer—like that of Virginia today.

Perhaps the most detailed record is that left by the last great glacier, the Wisconsin stage ice sheet, which slowly thinned and disappeared 10,000 to 20,000 years ago. It scoured lower rock hills into smoothed oval shape and rounded out deep notches like Crawford Notch. The striae it etched on smooth ledges, and the boulder trains it scattered in fan pattern over the state, show how it moved from northwest to southeast while the ice was still a few thousand feet thick. In the southern part of the state the till dragged by the ice was plastered on in streamlined drumlin hills. Then began the great thinning of the ice sheet; climate ameliorated. Meltwater flowing over the ice impinged on exposed hillsides cutting odd channels and potholes. Gravel carried by these torrents settled into chains of pools in the rotting ice, or along ice tubes, forming the kame knolls and esker ridges. When the ice had almost completely disappeared, valleys were filled with smooth layers of sandy outwash, or, in a few cases like the Connecticut Valley, long glacial lakes were dammed temporarily. Then with the disappearance of the heavy glacier, the land tilted up, lakes

spilled out, and the sea, swelled by meltwater, flooded slowly in over the land leaving a layer of marine clay. Thus closed the most remarkable episode in the surficial history of New Hampshire.

All of these stories have a direct bearing on our lives and the mineral wealth of the state. The more we know about the decaying glacier, the easier it is to discover the great sand and gravel deposits utilized for road construction and concrete. From the marine clays in southeastern New Hampshire, and the glacial lake clays, brick industries have sprung. Peat is dug from bogs and marshes for horticultural needs. Special moulding or glass sands can be found. Another most vital resource is groundwater; the search for it grows constantly. Then there is the need to cope with natural disasters. The shifting of river courses must be understood to locate and protect bridges and roads. Shoreline changes and ice shove must be understood to protect beach homes and wharves. The nature of the subsoil beneath roads must be judged to protect them from frost heaving every spring. Thus the interesting study of ancient glaciers, lakes, rivers, and shorelines reaps value in dollars and cents.

The greatest value to the scientist or interested layman is his satisfaction in discovering a new truth. Time will prove most of this story of surface features to be true, but some may be in error. Even now competent scientists are challenging the idea that each clay varve represents one year's worth of deposition. There is plenty of opportunity for new discoveries, or for detailed work in parts of New Hampshire not yet fully studied. In this fashion our knowledge of the ancient history of New Hampshire will grow and be corrected as the years go on.

GLOSSARY OF SCIENTIFIC TERMS

Boulder rampart A low ridge of boulders and dirt along a lake shore, pushed just above waterlevel by the shove of lake ice in the spring.

Boulder train The stones which are scattered by the glacier over a fan-shaped area from one particular small area of bed rock.

Cenozoic Era One long division of geologic time which lasted from 60,000,000 years ago until now.

Channel (glacial) A furrow cut in a hillside or across a high area by the meltwater from a glacier. Usually it contains only a tiny brook or marsh today.

Cirque The bowl-shaped head of a valley once gouged out by a mountain glacier.

Clastic dike A thin seam or sheet of clay, sand, or till squeezed like a wedge into cracked or rotten rock.

Crescentic marking A half-moon-shaped sheet or series of nesting fractures split in a smooth ledge by the pressure of a boulder under the heavy glacier.

Drift (glacial) Dirt of any sort carried by the glacier and deposited by the ice or by waters flowing from the ice.

Drumlin An elliptical hill, a few hundred or thousand feet long, generally made of glacial till. It is aligned and shaped by the motion of the glacier.

Erratic Any stone which is not the same kind of rock as the bedrock beneath it because it was moved by the glacier.

Esker A crooked ridge, 10 to 100 or more feet high, composed of layered sands and gravels. It is deposited by glacial meltwater flowing between two ice walls.

Felsite A fine-grained light-colored igneous rock which contains invisibly small crystal grains of "acid" minerals. It once solidified rapidly from molten lava as in a volcano.

Fossil The preserved parts or replica or trace of an ancient animal or plant encased in rock.

Gneiss A metamorphic rock made of crystal grains some of which are aligned or gathered in bands. These are created from some earlier rock by heat and pressure underground.

Granite A coarse-grained, light-colored igneous rock which contains visible crystal grains of "acid" minerals including quartz. It once solidified slowly from molten rock in a chamber deep underground.

Igneous rock Rock such as felsite or granite which solidified directly from a hot molten condition.

Joint A small crack (often one of a series of parallel cracks) in solid rock produced by the shrinkage or contortion of that bedrock.

Kame An irregular mound, 5 to 100 or more feet high, containing layers of sand or gravel. It was deposited in a pool of meltwater surrounded by ice.

Kame terrace A deposit of layered sand and gravel shaped like a giant step against a valley side. It has a rather flat top for it is deposited by meltwater between melting glacier ice and higher land.

Kettle hole A depression, a few feet to many tens of feet deep, completely surrounded by higher land. It is produced by the melting away of an ice mass previously buried under the surrounding drift.

Loess Dust-size particles blown by wind. These usually settle like a sheet over the surface.

Meander A smooth horse-shoe-shaped bend in the channel of a river.

Mesozoic Era One long division of geologic time which lasted from 200,000,000 to 60,000,000 years ago.

Metamorphic rock Rock such as gneiss or quartzite which was altered from some earlier type by heat and squeezing within the earth's crust.

Monadnock One lone mountain which stands above the surrounding peneplain (or hilltops representing a peneplain) due to its resistance to erosion or remoteness from large streams.

Nunatak A rock peak sticking up through a sea of glacier ice.

Outwash plain A broad, almost flat-topped deposit of sand and gravel layers. It is built up by shifting streams of glacial meltwater.

Paleozoic Era One long division of geologic time which lasted from 500,000,000 to 200,000,000 years ago.

Peneplain An ancient plain cut nearly flat by erosion during millions of years. As seen now it has been uplifted and new valleys eroded into it, so that only the hilltops mark the level of the ancient surface.

Pleistocene Epoch The last relatively short division of geologic time, which is the Ice Age, beginning about 1,000,000 years ago. It is the latest part of Cenozoic Era.

Porphyry An igneous rock made of small crystal grains and a few scattered large crystals. It cooled from molten condition within the earth's crust.

Pothole A smooth circular hole a few inches to 20 feet across, drilled into a stream channel of solid bedrock by churning water.

Quartzite	A compact metamorphic rock composed mostly of crystal grains of the mineral quartz. It is produced from a sandstone by heat and pressure within the earth's crust.
Ring dike	A circular band on the earth's surface of any one kind of igneous rock squeezed up as a pipe-shaped sheet.
Rock drumlin	A smooth elliptical hill of bedrock a few hundred or thousand feet long. It is shaped and aligned by the grinding of a glacier.
Runoff	Water which flows over the surface of the ground as streams.
Schist	A metamorphic rock composed of flakes of mineral packed together in regular alignment. It is produced from other fine-grained rocks by squeezing and heat within the earth's crust.
Sheepsback	A smooth elliptical knob of solid bedrock a few feet or tens of feet long. It is smoothed and aligned by the abrading ice.
Spit	A narrow promontory of sand built out from a shore by the wash of waves.
Striation (glacial)	A tiny scratch etched into smooth bedrock by a stone dragged under the glacier.
Syenite	A coarse-grained light-colored igneous rock like granite but lacking the mineral quartz. It was produced deep in the earth's crust by the slow cooling of molten rock.
Till	That kind of drift (dirt) scraped up and deposited directly by a glacier which contains particles of all sizes from clay to stones.
Tombolo	A bar of sand which ties one island to another or to the mainland. Ordinarily it is gathered by the wash of waves.
Varve (clay)	Thin layers of silt and clay occurring in regular alternation. Each pair of layers, consisting of a silt layer grading upward into a clay layer, represents the settling of a sediment during one year at the bottom of a glacial lake.
Water table	The invisible buried surface of completely water soaked dirt or rock underground.
Wisconsin Stage	The shortest division of geologic time lasting from 50,000 to 10,000 years ago. It is the part of the Pleistocene Epoch when the last great ice sheets existed.

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